

NASA CR-145137

FINAL TECHNICAL REPORT

**MONITORING AIR POLLUTION
FROM SATELLITES (MAPS)**

REPORT NO. 25435-6001-RU-00

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VOLUME 2
APPENDICES

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By

TRW

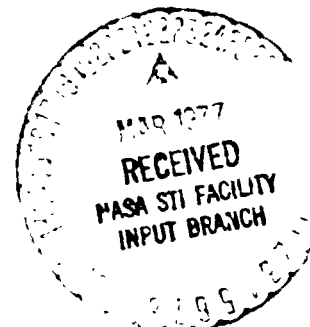
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For

NASA

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APPENDIX A

DESIGN ANALYSIS REPORT, SIGNAL PROCESSING CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides design analysis documentation for the signal processing circuitry of the MAPS breadboard electronics.

2.0 CIRCUIT REQUIREMENTS

The signal processing circuit implementation is per the block diagram, figure 1 with the individual block requirements as delineated below:

2.1 Input Buffers

Each of 3 composite scene and balance reference signals from the sensor head shall be received via a shielded twisted pair with a differential buffer stage.

- Buffer gain = $0.5 \pm 2\%$
- Dynamic range = ± 10 volts
- $(S_1 + R_1)$ and $(S_3 + R_3)$ buffer shall be non-inverting and the $(S_2 + R_2)$ buffer shall be inverting.

2.2 AGC Attenuators

Per the block diagram, 2 analog multipliers shall be used as AGC attenuators to control the gain over a range of $\pm 25\%$ around unity gain. The gain control voltage is the ± 10 volt output of the AGC control integrator.

The transfer function shall be:

$$e_o/e_{in} = 1 + K_{ATT} V_C$$

where V_C = AGC integrator control voltage

K_{ATT} = Attenuator scaling constant

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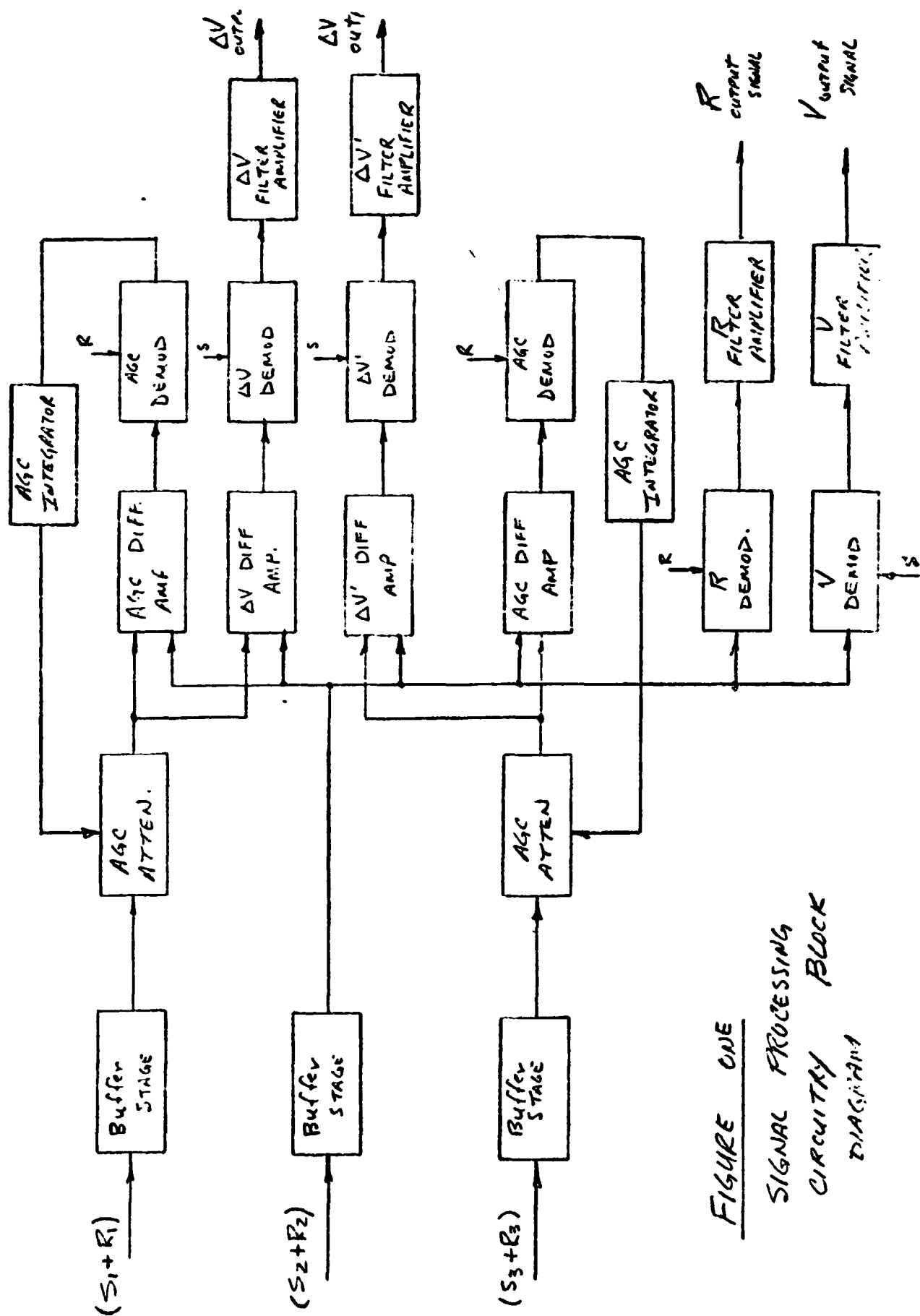


FIGURE ONE
SIGNAL PROCESSING
CIRCUITRY BLOCK
DIAGRAM

2.3 AGC Loop Scaling

The AGC loops shall have a difference amplifier, a R timed synchronous demodulator and an op-amp integrator. The total AGC loop gain and integrator time constant shall be such that the AGC loop time constant is 20 seconds when the R component of the buffer amplifier input signal is one volt peak to peak.

2.4 R Output Signal Scaling

The R component of the $(S_2 + R_2)$ signal shall be demodulated, amplified and filtered as the R output signal. Gain scaling shall be such that the d.c. output is 2.5 volts per volt peak to peak square wave input to the $(S_2 + R_2)$ buffer stage.

The output shall be filtered by an amplifier having 2 single order lags at 0.2Hz.

2.5 V Output Signal Scaling

The S component of the $(S_2 + R_2)$ signal shall be demodulated, amplified and filtered as the V output signal. Gain scaling shall be such that the dc output is 1.0 volts dc per volt peak to peak square wave input to the $(S_2 + R_2)$ buffer stage.

The output shall be filtered by 2 single order lags at 0.2 Hz.

2.6 ΔV and $\Delta V'$ Signal Scaling

The difference in the gain adjusted S_1 and S_2 signal components shall be obtained, demodulated, amplified and filtered as the ΔV output signal. The difference in the gain adjusted S_3 and S_2 signals provides the $\Delta V'$ output.

The gain scaling for each signal shall be such that the dc output is 22.5 volts dc per volt peak to peak signal difference referred to the buffer amplifier inputs.

The outputs shall be filtered by 2 single order lags at 0.2 Hz

3.0 CIRCUIT DESCRIPTION AND ANALYSIS RESULTS

Each of the individual circuits is described briefly below. The attached circuit analyses provide an assessment of circuit performance. The circuits are also shown on sketch schematics SK-MAPS-BB-102 and 103.

3.1 Input Buffer Stages

This stage consists of a HA2-2700 operational amplifier with a gain of ± 0.5 depending upon which input is used as the high side.

The feedback resistance is shunted with a selectable rolloff capacitor which is used to adjust the phase delays between the S_2 and S_1 or S_3 channel.

3.2 AGC Attenuator Stages

The AGC attenuation function is implemented with an integrated circuit analog multiplier. (Analog Devices AD 530L).

The AGC control input is fed both a +10 volt reference voltage and the output of the AGC integrator stage through a resistive summing network. Hence the nominal gain with no AGC integrator voltage is unity.

3.3 Difference Amplifier Stages

Each of the four differencing amplifiers uses a low power Harris HA2-2700 IC operational amplifier.

The AGC loop balance signal difference gain is 10. The ΔV and $\Delta V'$ signal difference gain is 15.

Small (0-50 ohm) selectable series resistors in the ΔV and $\Delta V'$ stage input circuits are used to match these difference circuits to the AGC balance loop. Resistor values are selected in test to provide a maximum reduction in the effect of the V signal upon the ΔV and $\Delta V'$ outputs.

3.4 Demodulator

All six of the signal processing demodulator circuits employ an identical circuit Topology.

The gain of a LM108A op-amp is switched between ± 1 by a DG129 FET switch integrated circuit which is driven from the appropriate drive reference signal (S or R). Pages 5 thru 8 of analysis attachment A review the demodulator performance characteristics.

3.5 AGC Loop Integrators

Each of the 2 AGC balance loops utilize an operational amplifier type RC integrator.

The operational amplifier consists of a 2N5196 dual FET stage followed by a LM108A IC op-amp.

The RC integration time constant is set by a 845K resistor and a 2.2 μ fd mylar feedback capacitor.

Analysis pages 9 thru 13 cover the AGC integrator performance.

3.6 Output Filter Amplifiers

Each of the output filter amplifiers uses a LM108A IC op-amp in an active filter circuit to provide two single order lags at 0.2 Hz while providing the necessary gain.

Analysis pages, 14 thru 25, provide a complete performance analysis of the R, V, ΔV , and $\Delta V'$ output filter amplifier performance.

3.7 OVERALL PERFORMANCE

The analysis results in attachment B show how an overall AGC loop time constant of 20 seconds is achieved and reviews the various output scale factors, offsets and scale factor stabilities.

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ATTACHMENT A - 25 PAGES

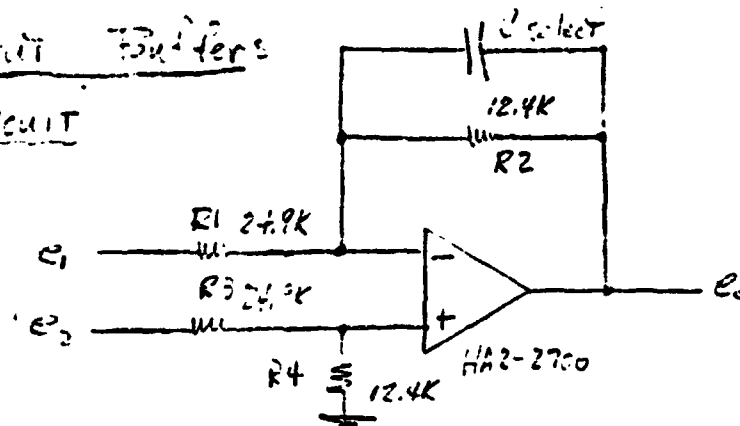
SIGNAL PROCESSING CIRCUITS

- INPUT Buffer
- AGC ATTENUATOR (ANALOG MULTIPLIER)
- Difference Amplifiers
- DEMODULATORS
- AGC INTEGRATORS
- OUTPUT FILTER AMPLIFIERS

TRW SYSTEMS GROUP		PREPARED BY: <i>R. J. E.</i>	ATTACHMENT	PAGE 1 OF 1
PROJECT AAPS	SUBJECT SIGNAL PROCESSING CIRCUITS	DATE		

INPUT Buffers

CIRCUIT



$$\text{GAIN TO } E_1 = -\frac{R_2}{R_1} = -0.5$$


$$\text{GAIN TO } E_2 = \left(1 + \frac{R_2}{R_1}\right) \left(\frac{R_4}{R_3 + R_4}\right) = (1.5) \left(\frac{1}{3}\right) = +.5$$

- For $(E_1 + R_1)$ AND $(E_3 + R_3)$ inputs, signal is fed to non-inverting input.
- For $(E_2 + R_2)$ input, signal is fed to inverting input.
- Response rolloff capacitor is selectable to adjust signal phase delay.

Typical value = 100pf

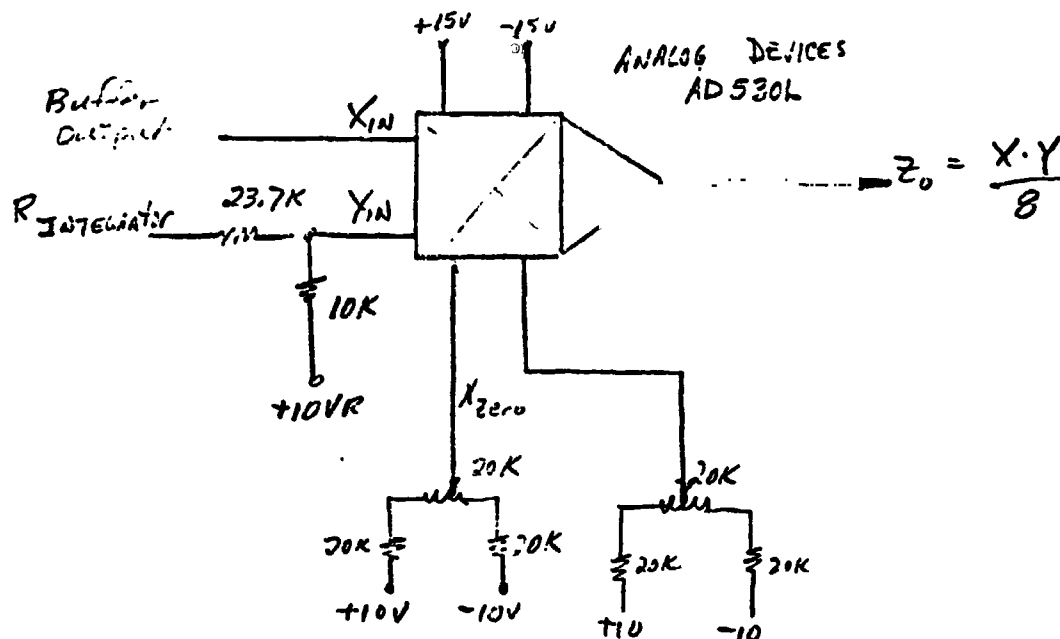
$$\text{So } f_{\text{rolloff}} = \frac{1590 \times 10^{-4}}{12.4K \times 100 \times 10^{-12}} = 128Kc$$

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PROJECT MADE	SUBJECT SIGNAL PROCESSING Circuits	DATE		

ANALOG MULTIPLIER — ATTENUATOR STAGE

1) CIRCUIT



2) MAXIMUM $X_{INPUT} = \pm 10V$ TO Buffer Amp
 $= \pm 5V$ TO Multiplier.

3) GAIN CONTROL — Y_{INPUT} VOLTAGE:

- for unity GAIN, Y_{INPUT} needs to be +3VOLTS.
- for gain of 0.75, Y_{INPUT} needs to be +6VOLTS.
- for gain of 1.25, Y_{INPUT} needs to be +10VOLTS.

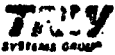
So DYNAMIC RANGE of AGC Integrator VOLTAGE is found:

$$Y_{IN} = \left(\frac{23.7}{33.7} \right) \cdot 10 + \left(\frac{10}{33.7} \right) \cdot V_{INT}$$

$$V_{INT} = \frac{33.7}{10} \left[Y_{IN} - \left(\frac{23.7}{33.7} \right) \cdot 10 \right] = \left(\frac{33.7}{10} \right) Y_{IN} - 23.7$$

So The Required V_{INT} RANGE = -3.5V TO +10V.

... and AGC Integrator A-8

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PROJECT M.F.	SUBJECT ANALOG PROCESSING CIRCUITS	DATE		

ANALOG MULTIPLIER - AGC ATTENUATOR Stage Cont.

3) output offset - dc VOLTAGE

Trimmed to zero initially

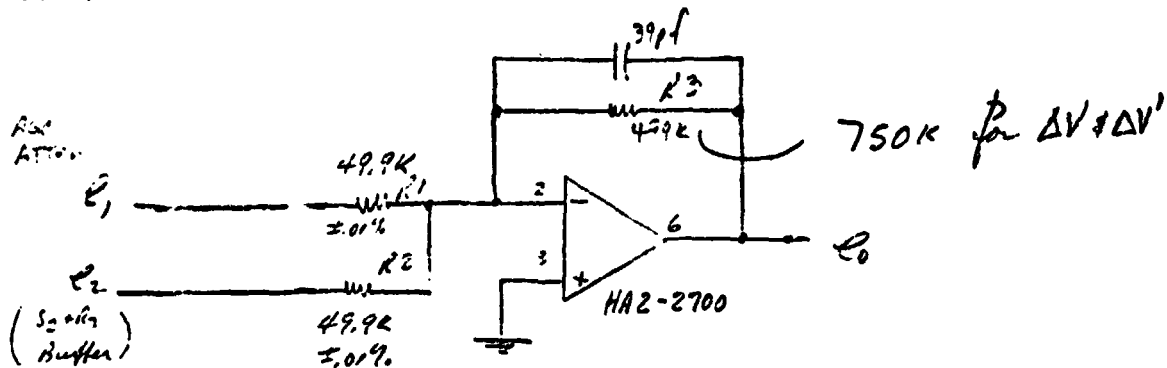
VARIES 1mV/°C MAX per AD530L Spec Sheet

± over ±25°C Temp RANGE, $\epsilon_{idc} = \pm \underline{25mV}$

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AGC & ΔV Difference Amplifiers



$$e_0 = -\frac{R_3}{R_1} e_1 - \frac{R_3}{R_2} e_2 = -R_3 \left(\frac{e_1}{R_1} - \frac{e_2}{R_2} \right)$$

$$= -10(e_1 - e_2) \text{ for AGC}$$

$$= -15(e_1 - e_2) \text{ for } \Delta V \text{ & } \Delta V'$$

RATIO of R_1 TO R_2 DETERMINES DIFFERENCING ACCURACY.

BOTH ARE KBR 56L RESISTORS WITH .01% INITIAL TOLERANCES.

$\Delta V \text{ & } \Delta V'$ DIFFERENCING IS FURTHER TRIMMED WITH SMALL (0-500) SERIES RESISTORS FOR OPTIMUM INITIAL BALANCE.

AVERAGE Temp Coeff. of Resistance = $\pm 10 \text{ ppm}/^\circ\text{C}$

SO DIFFERENCING ACCURACY IS:

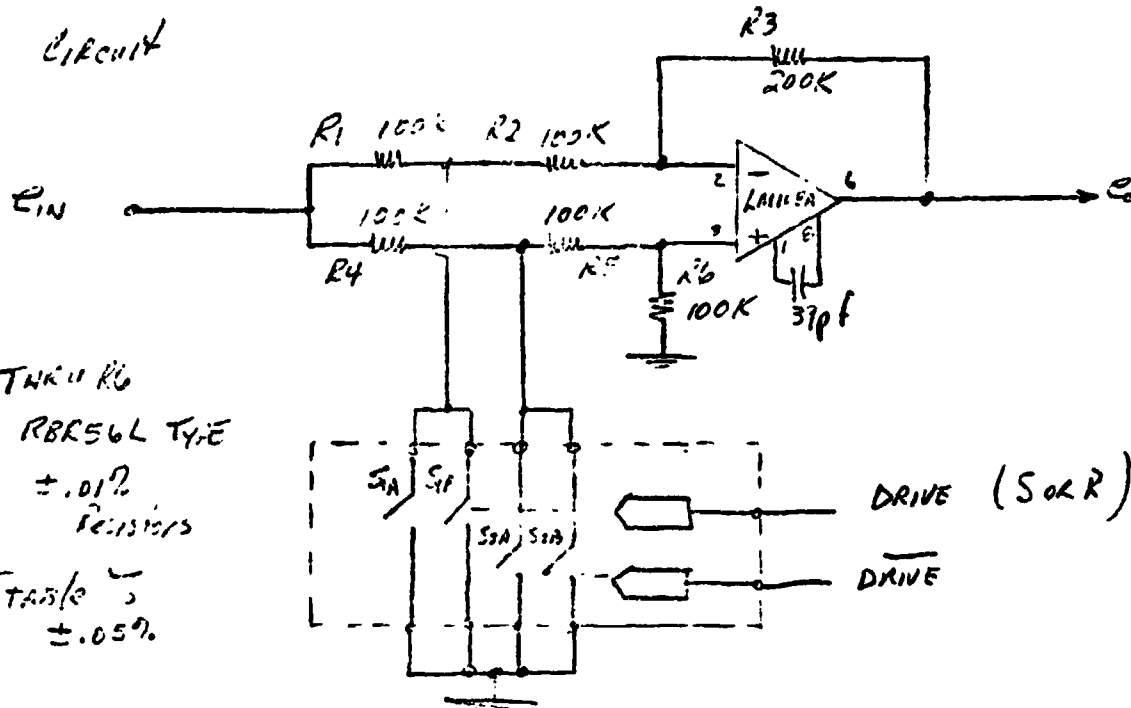
$$= \pm .001\% / ^\circ\text{C}$$

$$= \pm .025\% \text{ over } \pm 25^\circ\text{C Temp Range}$$

HIGH FREQ ROLLOFF $\approx 8.2 \text{ Kc}$

Full Wave Modulation Circuit for $V, R, \Delta V, \Delta V'$ AND A_0

1) Circuit



R_1 THROUGH R_6
= RESISTOR TYPE

$\pm 0.1\%$
Resistors

Stable $\pm 0.05\%$

GAIN is alternately switched between +1 and -1

2) "IDEAL SWITCH" GAIN EQUATIONS:

for inverting case S_1 is off, S_2 is on

$$\frac{E_O}{E_{IN}} = \frac{-R_5}{R_1 + R_2} = -1$$

for non-inverting case, S_1 on, S_2 off
Then

$$\frac{E_O}{E_{IN}} = \left(1 + \frac{R_3}{R_2}\right) \left(\frac{R_6}{R_4 + R_5 + R_6}\right) = (1 + 2) \left(\frac{1}{3}\right) = +1$$

So A 1Vpp input will give +0.5V out.

DEMODULATORS Continued

3) Effects of non-ideal switches

Two switches in Parallel

Assume: $\bar{R}_{SW} = \frac{50\Omega}{2} = 25\Omega$

$R_{off} = \frac{5V}{10nA} = 500 \text{ Megohm}$

So inverting gain is:

$$\begin{aligned} \frac{e_o}{e_{in}} &= -\left(\frac{R_{off}}{R_1 + R_{off}}\right)\left(\frac{-R_3}{R_2 + R_1 \parallel R_{off}}\right) + \left(1 + \frac{R_3}{R_1 \parallel R_2}\right)\left(\frac{R_6}{R_5 + R_6}\right)\left(\frac{R_{SW}}{R_4 + R_{SW}}\right) \\ &= -(.9998)\left(\frac{200K}{100K + 100K}\right) + (2)(.5)\left(\frac{25}{100025}\right) \\ &= -.9998 + .00025 \\ &= \underline{-.99955} \quad \text{or } -.045\% \text{ gain change} \end{aligned}$$

AND non-inverting gain is:

$$\begin{aligned} \frac{e_o}{e_{in}} &= -\left(\frac{R_3}{R_2}\right)\left(\frac{\bar{R}_{SW}}{R_1 + \bar{R}_{SW}}\right) + \left(1 + \frac{R_3}{R_2}\right)\left(\frac{R_6}{R_5 + R_6 + R_1 \parallel R_{off}}\right)\left(\frac{R_{SW}}{R_4 + R_{SW}}\right) \\ &= -2\left(\frac{25}{100025}\right) + (3)\left(\frac{1}{3}\right)\left(\frac{500M\Omega}{500M + 1M\Omega}\right) \\ &= -4.99 \times 10^{-4} + .9998 = \underline{.9993} \quad \text{or } -.07\% \text{ gain change} \end{aligned}$$

Note That since \pm parameter change
Effects \pm GAIN ONLY Differences in
switch RESISTANCES cause offset in output.

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4) Effect of mis-matched Resistors

OVER Temperature & Environment $\frac{\Delta R}{R} = \pm 0.05\%$

for
initial
tolerance

Effect on $-G_{ss}$:

$$\frac{\Delta G_{-}}{G_{-ss}} = \left[\pm \left(\frac{\Delta R_3}{R_3} \right)^2 \pm \left(\frac{R_1}{R_1 + R_2} \right)^2 \left(\frac{\Delta R_1}{R_1} \right)^2 + \left(\frac{R_2}{R_1 + R_2} \right)^2 \left(\frac{\Delta R_2}{R_2} \right)^2 \right]$$

$$= \left[\pm (0.05)^2 \pm (.075)^2 \pm (.025)^2 \right]^{1/2} = \pm 0.067\%$$

Effect on $+G_{ss}$:

$$\frac{\Delta G_{+}}{G_{+ss}} = \left\{ \pm \left(\frac{R_3/R_2}{1 + R_3/R_2} \right)^2 \left(\frac{\Delta R_3}{R_3} \right)^2 \pm \left(\frac{R_3/R_2}{1 + R_3/R_2} \right)^2 \left(\frac{\Delta R_2}{R_2} \right)^2 \right.$$

$$\left. \pm \left(\frac{R_4 + R_5}{R_4 + R_5 + R_6} \right)^2 \left(\frac{\Delta R_6}{R_6} \right)^2 \pm \left(\frac{R_4}{R_4 + R_5 + R_6} \right)^2 \left(\frac{\Delta R_4}{R_4} \right)^2 \pm \left(\frac{R_5}{R_4 + R_5 + R_6} \right)^2 \left(\frac{\Delta R_5}{R_5} \right)^2 \right\}$$

$$\frac{\Delta G_{+}}{G_{+ss}} = \left\{ \pm (.033)^2 \pm (.033)^2 \pm (.033)^2 \pm (.0167)^2 \pm (.0167)^2 \right\}$$

$$= \pm 0.067\%$$

Demodulators Cont

Effective output effect

- Due to op-amp offsets
- Due to mismatched Gain Response to dc input:

$$\text{max. dc input} = \underbrace{15}_{\text{diff Amp Gain}} \times \underbrace{\pm 25\text{mV}}_{\text{multiplier offset}} = \pm 375\text{mV}$$

- LM108A $e_{os} = \pm 5\text{mV}$ $\Delta e_{os} = 5\mu\text{V}/^\circ\text{C} = \pm 0.65\text{mV max}$
 $i_b = 3\text{nA max}$ $i_{os} = .4\text{nA}$
 $e_{os}/i_{os} = .4\text{nA} \times 100\text{K} = .04\text{mV insignificant}$

- MAX^{output} offset due to LM108A offset

$$= .65\text{mV} \times 3 = \pm 1.95\text{mV max}$$


$$\text{max VARIATION} = (.15 + .04)(3) = \pm .57\text{mV}$$

Mis-matched Gain Response to $\pm 375\text{mV}$ dc input

$$\text{is: } \pm .06\% \times 3 \times \pm 375\text{mV} = \pm 0.68\text{mV}$$

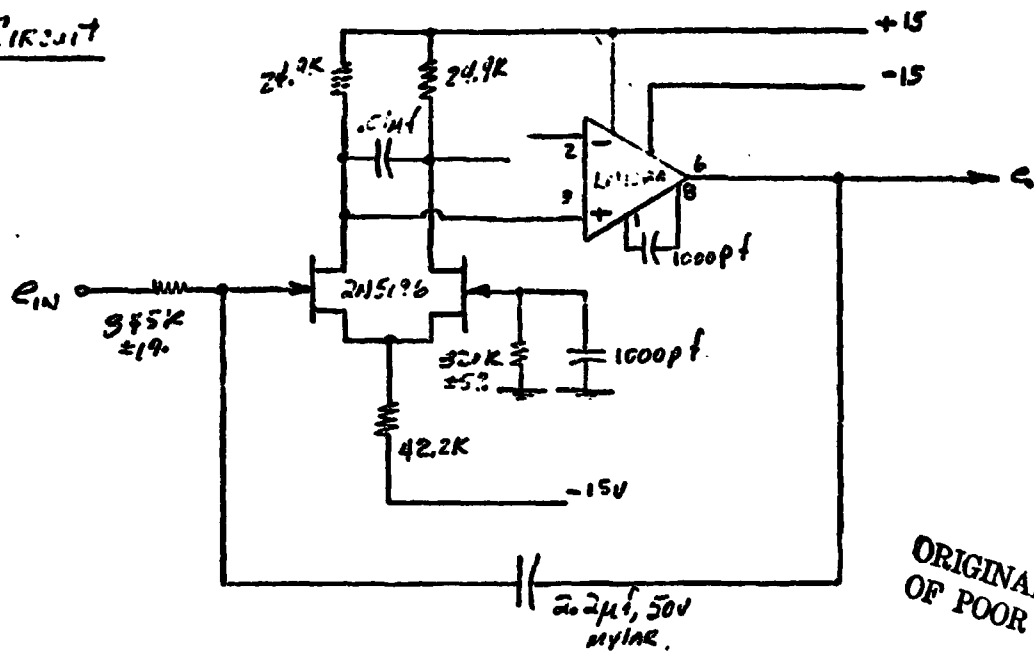
So TOTAL output offset VARIATION

$$V_{ss} = \left[(\pm 0.68\text{mV})^2 + (\pm 0.57\text{mV})^2 \right]^{1/2} = \pm 0.88\text{mV}$$

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PROJECT NAME:	SUBJECT: SIGNAL PROCESSING CIRCUITS	DATE:		7 OF

AGC Loop Integrators

1) Circuit



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2) FET BIASING —

a) For V_p of 2N5196 $\approx 2V$, $V_{R3} = 17V$

$I_{R3} = .4mA \therefore I_D (\text{each side}) = 200\mu A$

b) $V_{DRAIN} = V_{CC} - I_D R_1 = 15 - .2mA \times 24.9K = 10V$

c) FET Stage GAIN $\approx g_m R_L = 1000 \times 10^{-6} \times 25 \times 10^3 \approx 25$

3) Input offsets — for 2N5196 dual fet

$\Delta V_{GS} = \pm 5mV$, $\frac{\Delta V_{GS}}{\Delta T} = \pm 5\mu V/^{\circ}C$

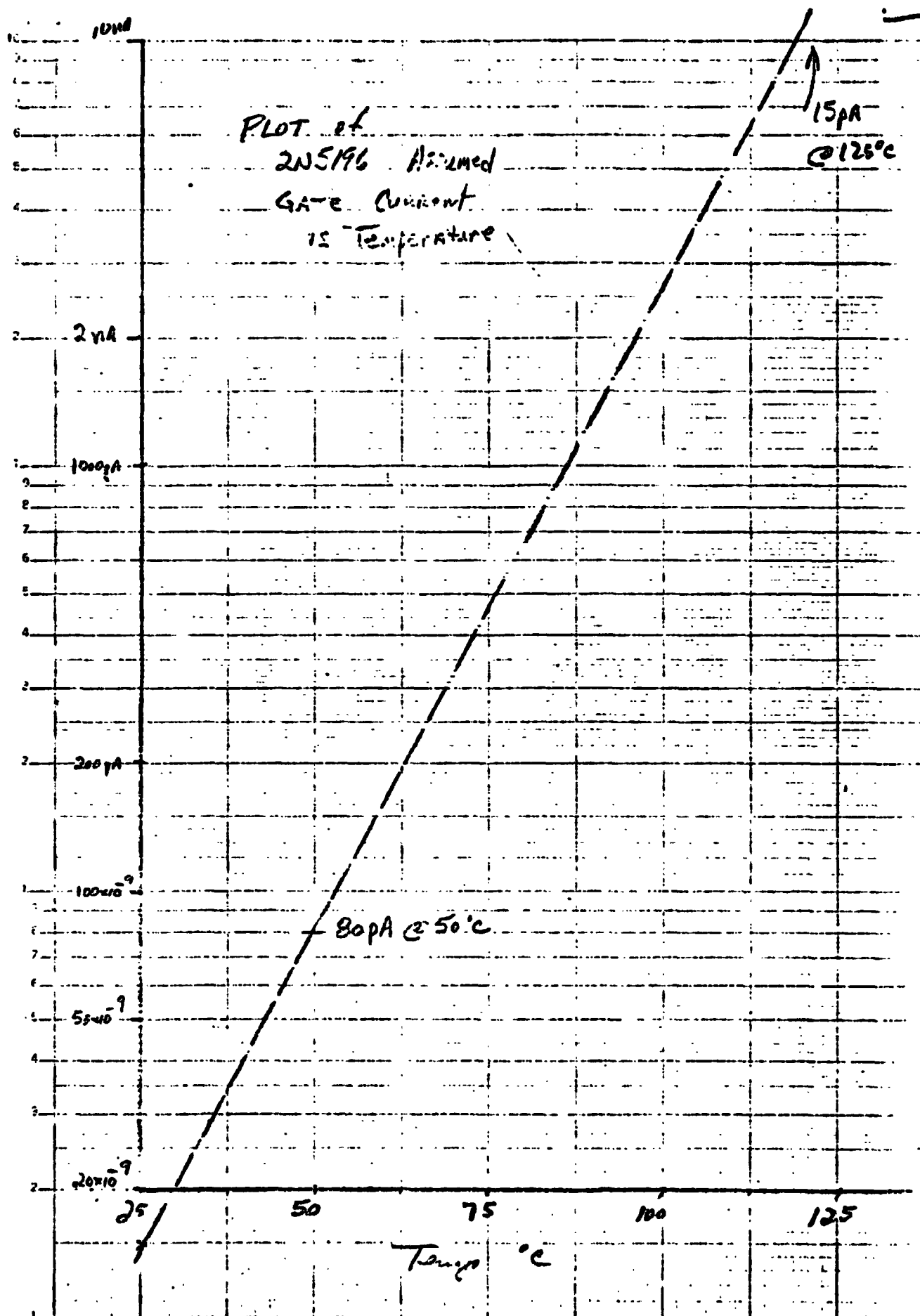
$I_{G1} = 15\mu A @ 25^{\circ}C$
 $= 15\mu A @ 125^{\circ}C$

} from this we get $80pF @ 50^{\circ}C$
(see GRAPH PAGE 2)

we will assume

$|I_{GS1} - I_{GS2}| = \frac{1}{3} I_{G1} = \underline{\underline{27\mu A}}$

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PROJECT NAME	SUBJECT SIGNAL PROCESSING CIRCUITS	DATE	

ABC Integrator: Continued

3) Therefore THE FIXED INITIAL offset ARE:

$$E_{os}|_{t=0} = \left\{ \underbrace{(\pm 5mV)}_{E_{os}} + \underbrace{(80pA \times 649K)}_{I_G \times R_{IN}} \right\}^{1/2}$$

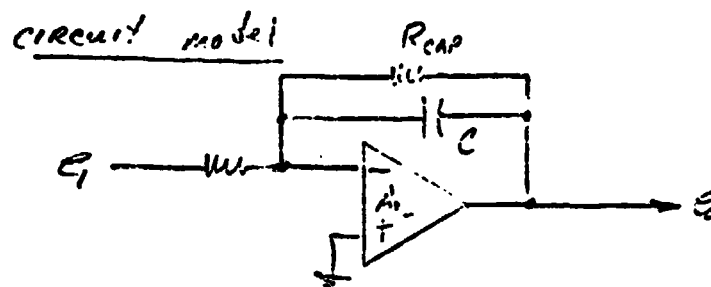
$$= \underline{\underline{5mV}}$$

VARIATIONS IN input offset over $\pm 25^\circ C$ Temp. Range

- ΔE_{os} of $I_G = 5\mu V/^\circ C \times \pm 25^\circ C = \pm .125mV$
- ΔE_{os} due to I_{os}
 $= .65mV \times \pm 27pA = .02mV$

$$V_{ss \text{ Total}} = \left[(.125)^2 + (.02)^2 \right]^{1/2} = \underline{\underline{\pm .127mV}}$$

4) Integrator Transfer Function

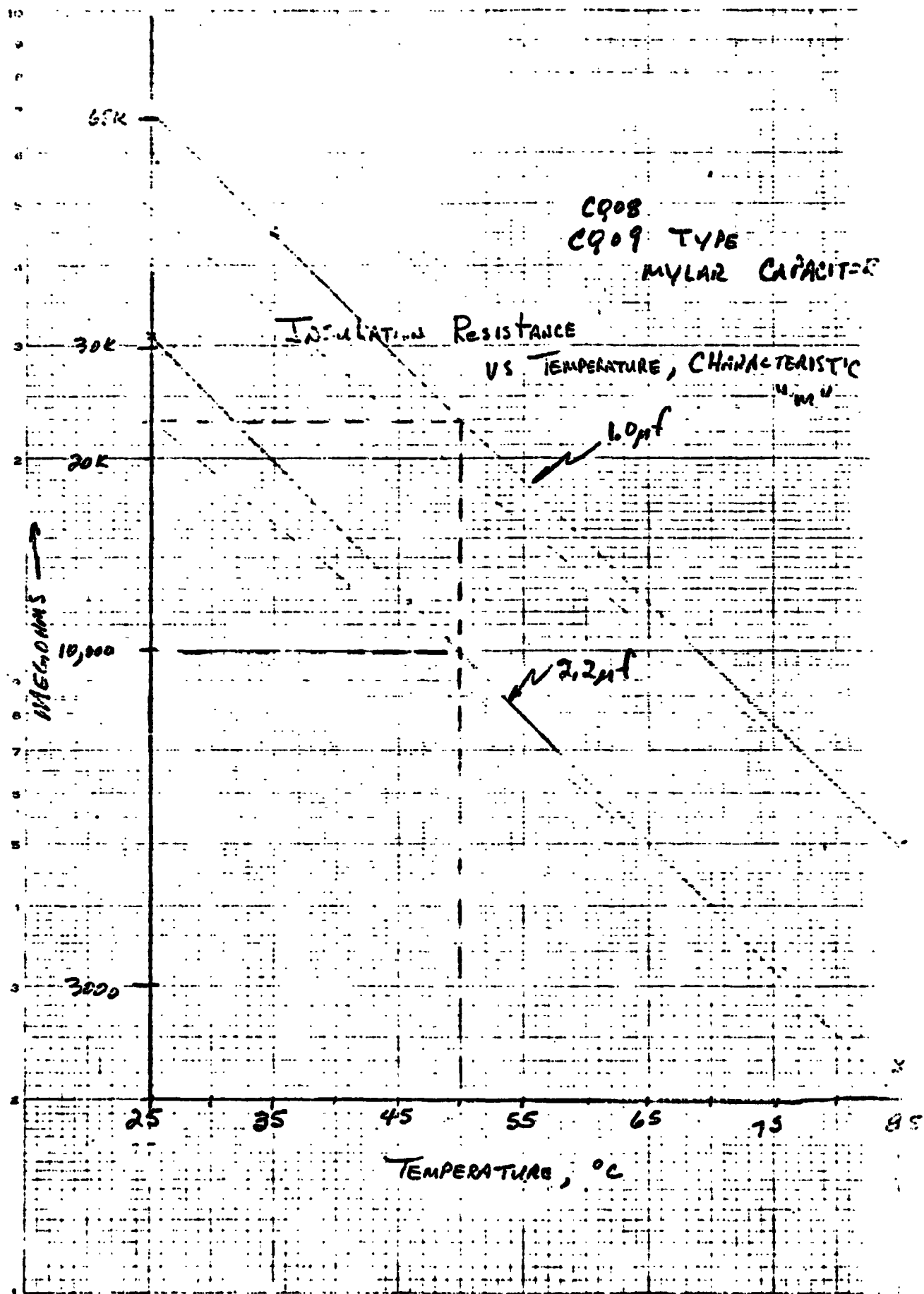


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- A_{OL} of Amplifier $\geq 25 \times 40K \geq 10^6$
- Z_{in} of FET stage $\geq \frac{10V}{80pA} \geq 10^4 M\Omega$
- μA_{741} Cap insulation resistance (See graph)
 $\geq 68K M\Omega$ at $25^\circ C$
 $\geq 5K M\Omega$ at $75^\circ C$
 $\text{extrapolated to } 50^\circ C \geq 23K M\Omega$

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PROJECT A-19	SUBJECT Signal Processing Circuits	DATE		

ASL Integrating Ckt.

4) Integrating Transfer Function Ckt.

approx. low frequency Resistance Ckt.
So 2.2μf feedback capacitor

$$\begin{aligned} |R| &\geq 30.9 \text{ K}\Omega @ 25^\circ\text{C} \\ &\geq 20.5 \text{ K}\Omega @ 75^\circ\text{C} \\ &\geq 10.5 \text{ K}\Omega @ 50^\circ\text{C} \end{aligned}$$

So MAX. DC GAIN

$$= \frac{30.9 \text{ K}\Omega}{.85 \text{ M}\Omega} = \underline{36 \text{ K}} \ll A_{OL} \text{ of } 10^6$$

AND $R_{IN} \gg R_i$

Therefore Transfer function basically determined by feedback components as

$$G(s) = \frac{R_o}{R_{IN}} \left(\frac{1}{s R_o C + 1} \right) = \frac{1}{R_i C} \left(\frac{R_o C}{s R_o C + 1} \right)$$

$$= \frac{1}{R_i C} \left(\frac{(R_o/R_i)(R_i C)}{s \left(\frac{R_o}{R_i} \right) R_i C + 1} \right) = \frac{1}{T_i} \left(\frac{A_o T_i}{s A_o T_i + 1} \right)$$

where: $A_o = (R_o/R_i)$ & $T_i = 1/R_i C$

minimum Value of A_o is @ 50°C

$$A_o = \frac{10.5 \text{ K}\Omega}{.85 \text{ M}\Omega} = \underline{12,350}$$

and

$$T_i = .845 \mu\text{s} \cdot 2.2 \mu\text{f} = \underline{1.86 \text{ seconds}}$$

and

$$\frac{\Delta T_i}{T_i} = \sqrt{(\pm 17\%)^2 + (\pm 1.5\%)^2} = \underline{\pm 1.63\%}$$

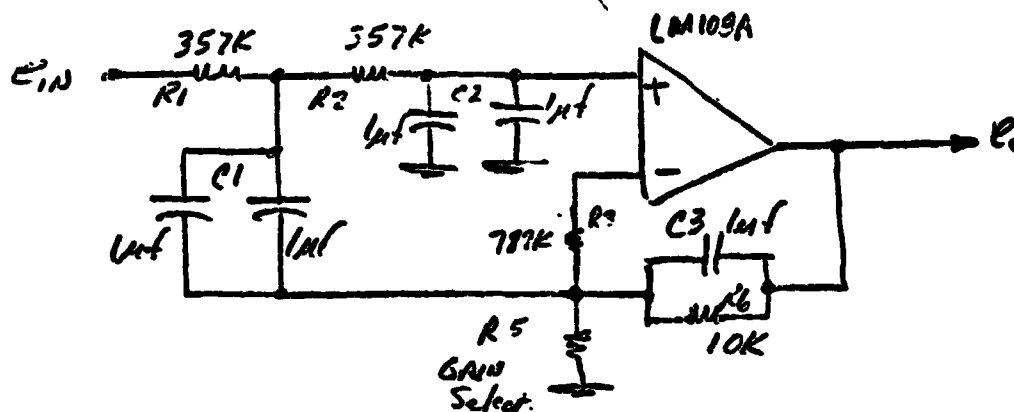
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OUTPUT FILTER AMPLIFIERS

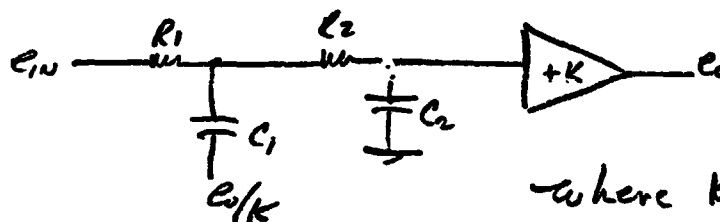
1) FUNCTION

GAIN SCALE & RATTLE filter

2) General Topology



3) Approximate AC Response Circuit.



where $K = \frac{R_5 + R_6}{R_5}$

THUS

$$E_O = K \left\{ \frac{(sR_1C_1E_O/K + E_1)}{sR_2C_2(sR_1C_1 + 1) + (sR_1C_1 + 1) + sR_1C_2} \right\}$$

Solving for E_O :

$$E_O = \frac{K C_1}{s^2 R_1 R_2 C_1 C_2 + s R_2 C_2 + s R_1 C_2 + 1} = \frac{K E_1}{(sR_1C_1 + 1)(sR_2C_2 + 1)} \text{ if } C_1 = C_2$$

ORIGINATOR MJO	DATE	TITLE OUTPUT FILTER AMPLIFIERS	ENGINEERING SKETCH TRW ONE SPACE MARK - RECORDING BOARD, CALIFORNIA
MJO		APPROX. AC Response	SK SHEET 14 OF A-20

SK

CHG LTR

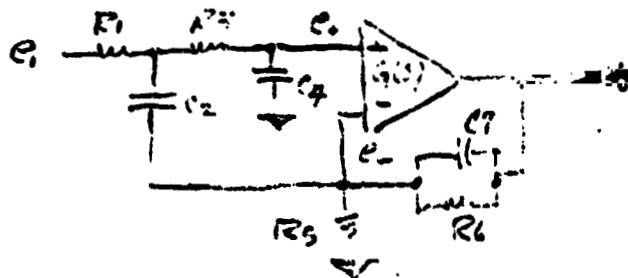
3. FILTER ACTS AS A Double LAG with
 Break freq = $\frac{1}{2\pi R_1 C_1}$
 with 357K & 2 μ f we get
 $f = \underline{0.223\text{Hz}}$ Nominal

Additional capacitor C3 in parallel with R6
 continues Roll off past 10Hz. See exact
 Analysis.

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ORIGINATOR LVE	DATE	TITLE	ENGINEERING SKETCH
		Output Filter	TRW
		Amplifiers	ONE BRACE PARK - REDWOOD CITY, CALIFORNIA
MJO		Airbox Ac Response	SK
			SHEET 1 OF

1. Circuit



$$e_o = G(s)[e_+ - e_-]$$

1) Define Variables in Linc Program

Let $AO = \text{OPAMP GAIN} = 3 \times 10^5$

$$A1 = R1$$

$$A2 = C2$$

$$A3 = R3$$

$$A4 = C4$$

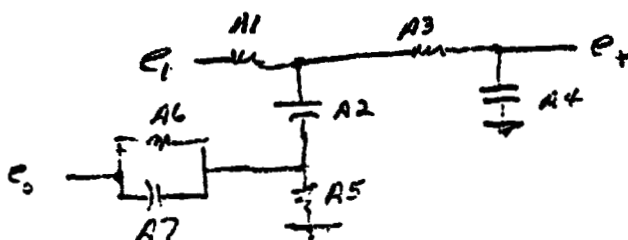
$$A5 = R5$$

$$A6 = R6$$

$$A7 = C7$$

$$A8 = T1 = \text{OP-AMP Low-Freq Corner} \approx .15 \text{ Sec}$$

2) Then At Non-inv. part we have:



Define Complex impedances

* 3001 $Z1 = \text{CMPLX}(0, -1/(\omega * A2))$

* 3002 $Z2 = \text{CMPLX}(0, -1/(\omega * A4))$

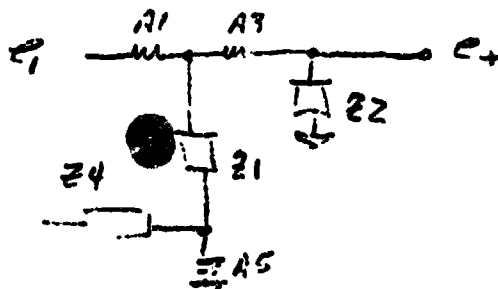
* 3003 $Z3 = \text{CMPLX}(0, -1/(\omega * A7))$

Then

* 3004 $Z4 = A6 * Z3 / (A6 + Z3)$

ORIGINATOR KFE	DATE	TITLE Output Filter Amplifiers	ENGINEERING SKETCH
		EXACT Gain/Frequency Response Analysis	TRW ONE SPACE PAPER - REDUCED GRADE PAPER
MJO			SK
			SHEET 11 OF

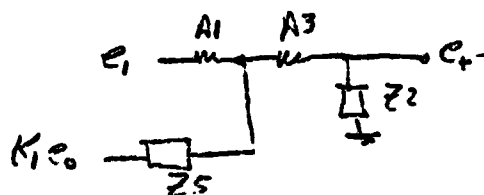
So AT NON-INV INPUT we have



Define the following:

* 3005 $K_1 = A5 / (A5 + Z4)$
 * 3006 $Z5 = Z1 + Z4 * A5 / (A5 + Z4)$

Then we have:



So

$$e_+ = \frac{Z2}{Z2 + A3 + \frac{A1 Z5}{A1 + Z5}} \left[e_1 \times \frac{Z5}{A1 + Z5} + \frac{K1e0 A1}{Z5 + A1} \right]$$

Again we define new variable: as follows

* 3010 $K_2 = (Z2 * Z5) / (Z5 * A1 + A1 * (Z2 + A3) + Z5 * (Z2 + A3))$

* 3015 $K_3 = (K1 * Z2 * A1) / (Z2 * (A1 + Z5) + A3 * (A1 + Z5) + A1 * Z5)$

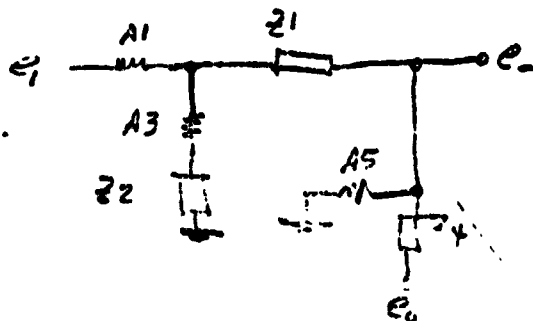
Thus we have:

$$e_+ = K_2 e_1 + K_3 e_0$$

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ORIGINATOR LFE	DATE	TITLE OUTPUT FILTER AMPLIFIERS (EXACT AC RESPONSE)	ENGINEERING SKETCH TRW ONE SHOCK PARK - ROSENBERG ROAD, CALIFORNIA
MJO	MAPS BB		SK
			SHEET 7 OF

3) AT THE MIXING POINT WE HAVE

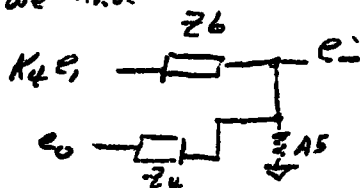


Define The following:

$$* 3020 \quad Z_6 = Z_1 + A_1 * (A_3 + Z_2) / (A_1 + A_3 + Z_2)$$

$$* 3025 \quad K_4 = (A_3 + Z_2) / (A_1 + A_3 + Z_2)$$

THEN we have



So by Superposition:

$$e_- = \frac{K_4 e_1 (A_5 + Z_4)}{(A_5 + Z_4) + Z_6} + \frac{e_- * (A_5 + Z_6)}{(A_5 + Z_6) + Z_4}$$

So define new constants

$$* 3030 \quad K_5 = (K_4 * A_5 * Z_4) / (A_5 * Z_4 + Z_6 * (A_5 + Z_4))$$

$$* 3035 \quad K_6 = (A_5 * Z_6) / (A_5 * Z_6 + Z_4 * (A_5 + Z_6))$$

THEN

$$e_- = K_5 e_1 + K_6 e_0$$

ORIGINATOR PFE	DATE	TITLE Output filter Amplifiers (Exact AC Response)	ENGINEERING SKETCH TRW ONE SPACE MARK - REWORKED MARK - CALCULATION
MJO			SK SHEET 1 OF

4) AT output $e_o = K_7(s) [e_+ - e_-]$

Define $K_7 = \frac{A_o}{T_1 s + 1}$ where $A_o = \text{open loop gain}$
 $T_1 = \text{main pole of op-amp}$

* 3010 $K_7 = A_o / \text{COMPLX}(1, \omega \times A_o)$

Substitution: $e_+ \& e_-$ we have

$$e_o = K_7 [K_2 e_1 + K_3 e_o - K_5 e_1 - K_6 e_o]$$

$$= K_7 [(K_2 - K_5) e_1 + (K_3 - K_6) e_o]$$

or:

$$e_o [1 + K_7 (K_6 - K_3)] = K_7 (K_2 - K_5) e_1$$

FINALLY

$$e_o / e_1 = \text{GAIN} = \frac{K_7 (K_2 - K_5)}{1 + K_7 (K_6 - K_3)}$$

So for Program

* 3200 $X = K_7 * (K_2 - K_5) / (1 + K_7 * (K_6 - K_3))$

ORIGINATOR <i>[Signature]</i>	DATE	TITLE	ENGINEERING SKETCH
		Output filter	TRW
		Amplifiers	ONE SHAW PARK • REDWOOD BEACH, CALIFORNIA
		(Exact Ac Response)	SK
MJO 11/11/65			SHEET / / OF

RSSWC1 Test Computer Program is Then:

LIST-FLTRAMP

500 FOR F = .001, .01, .02, .05, .08, .1, .2, .4, .6, 1, 2, 4, 8, 10, 20, 40
 2000 DATA C05, C57C0, Z5, X, C57C1, Z5, X, 1, 1E0, 1E4, 1E-6, .159
 2100 DATA C0, Z, 20, Z, 20, Z, 2, 20, Z
 2200 DATA A1, A1, C2, A3, C4, A5, A6, C7, T1
 2300 DATA "OUTPUT FILTER AMPLIFIER"
 3000 Z1=CMPLX(0, -1/(W*A2))
 3002 Z2=CMPLX(0, -1/(W*A4))
 3003 Z3=CMPLX(0, -1/(W*A7))
 3004 Z4=A5+Z3/(A6+Z3)
 3005 X1=A5/(A5+Z4)
 3006 Z5=Z1/(Z4+A5)/(A5+Z4)
 3010 K2=(Z5+Z5)/(Z5+A1+A1+(Z5+A3)+Z5*(Z5+A3))
 3015 X3=(X1+Z2+A1)/(Z2*(A1+Z5)+A3*(A1+Z5)+A1+Z5)
 3020 Z6=Z1+A1/(A3+Z2)/(A1+A3+Z2)
 3025 K4=(A3+Z2)/(A1+A3+Z2)
 3030 K5=(X4+A5+Z4)/(A5+Z4+Z6*(A5+Z4))
 3035 K6=A5+Z6/(A5+Z6+Z4*(A5+Z6))
 3040 K7=A0/CMPLX(1, W*A8)
 3200 X=X7*(X2+K5)/(1+K7*(K6+X3))

where data on line 2000 is for the
 R output filter amplifier.

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ORIGINATOR <i>SK</i>	DATE	TITLE output Filter Amplifiers	ENGINEERING SKETCH
		EXACT AC Response	TRW SPACE RESEARCH CORPORATION REDWOOD CITY, CALIFORNIA
MJO			SK SHEET 20 OF

Balance Signal (R) Filter Amp. Run

FREQ	GAIN-DB	TOL.	TOL.-DB	PHASE	TOL.-DB
1.00000E+00	2.00701E+01	.219	-.224	-.517	.100
1.00000E+02	2.00699E+01	.219	-.224	-5.170	1.027
1.00000E+04	2.00699E+01	.223	-.229	-10.019	2.029
1.00000E+06	1.96511E+01	.000	-.040	-25.448	4.679
1.00000E+08	1.96289E+01	.591	-.605	-39.746	6.529
1.00000E+10	1.84902E+01	.793	-.872	-48.249	7.290
1.00000E+12	1.49372E+01	1.511	-1.830	-64.449	8.140
1.00000E+14	7.24820E+00	1.980	-2.071	-123.040	7.821
1.00000E+16	-2.47587E+00	1.994	-2.592	-151.464	5.557
1.00000E+18	-5.96208E+00	1.996	-2.595	-158.127	4.704
1.00000E+20	-1.84611E+01	1.801	-2.275	-173.864	2.840
1.00000E+22	-2.48247E+01	1.229	-1.432	173.018	2.903
1.00000E+24	-2.96970E+01	.853	-.708	157.117	4.557
1.00000E+26	-3.10736E+01	.830	-.679	150.940	5.115
1.00000E+28	-3.47518E+01	1.022	-1.159	100.078	5.558
1.00000E+30	-3.98037E+01	1.092	-1.658	112.477	3.924

THE ARGUMENTS AND TELEPRICES ARE:

R0	R0	300000	30	R5	R5	1100	2
R1	R1	357000	2	R6	R6	10000	2
R2	R2	.2E-05	20	R7	R7	.1E-05	20
R3	R3	357000	2	T1	R8	.159E+00	20
R4	R4	.2E-15	20				

PROGRAM: OUTPUT FILTER AMPLIFIER
07.20.75. 07.44.04.

DC GAIN = 20dB or 10
See GRAPH of Response Plot.

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ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
		output Filter Amps	TRW
			ONE SPACE PAPER - PROOFED GRADE - CALIFORNIA
MJO		R Signal Amp. AC Response	SK
			SHEET 21 OF

Common Scene(S) Signal Filter Amp Run

$$R_g = 3.32K$$

PIS ANALYSIS

Output Filter Amp

CHG LTR

SK

FREQ	GAIN(DB)	TEL	TEL(DEC)	PHASE	TEL(DEC)
1.00000E-02	1.20370E+01	.182	-.186	-.517	.103
1.00000E-02	1.20499E+01	.183	-.187	-5.164	1.027
2.00000E-02	1.19980E+01	.187	-.192	-10.308	2.029
5.00000E-02	1.18408E+01	.308	-.319	-25.421	4.879
8.00000E-02	1.16225E+01	.579	-.621	-39.702	6.529
1.00000E-01	1.04825E+01	.783	-.861	-48.595	7.293
2.00000E-01	6.98548E+00	1.502	-1.818	-84.341	8.143
4.00000E-01	-2.48888E-01	1.834	-2.328	-122.830	7.821
8.00000E-01	-1.00404E+01	1.898	-2.432	-151.080	5.560
1.00000E+00	-1.00004E+01	1.856	-2.363	-157.877	4.709
2.00000E+00	-2.28487E+01	1.440	-1.727	-173.296	2.847
4.00000E+00	-2.81488E+01	.759	-.832	173.373	2.884
8.00000E+00	-3.11223E+01	.488	-.494	157.219	4.545
1.00000E+01	-3.19056E+01	.542	-.578	151.002	5.108
2.00000E+01	-3.50188E+01	1.018	-1.154	130.095	5.557
4.00000E+01	-3.98594E+01	1.392	-1.658	112.484	3.926

THE ARGUMENTS AND TOLERANCES ARE:

R0	R0	300000	30	R5	R5	3320	2
R1	R1	357000	2	R6	R6	10000	2
C2	R2	.2E-05	20	C7	R7	.1E-05	20
R3	R3	357000	2	T1	R8	.159E+00	20
C4	R4	.2E-05	20				

PROGRAM: OUTPUT FILTER AMPLIFIER
07/20/75. 07.51.48.

DC GAIN = 12db = 4

See Graph of Response Plot

ORIGINATOR MJO	DATE	TITLE output Filter Amps	ENGINEERING SKETCH
			TRW ONE SPACE PARK • REDWOOD CITY, CALIFORNIA
		VSIGNAL Amplifier	SK
MJO			SHEET 22 OF

ΔV & $\Delta V'$ SIGNAL FILTER AMPLIFIERS

$$R_S = 2.00K$$

MSB ANALYSIS

ΔV & $\Delta V'$ output Filter Amp

SK

FFED	GAIN(DB)	+TOL.	-TOL.(DB)	PHASE	TOL(DEC)
1.00000E-02	1.55827E+01	.202	-.207	-.517	.101
1.00000E-02	1.55455E+01	.203	-.207	-5.167	1.027
2.00000E-02	1.54935E+01	.207	-.212	-10.314	2.029
5.00000E-02	1.51084E+01	.320	-.332	-25.436	4.679
8.00000E-02	1.45155E+01	.586	-.628	-39.726	6.523
1.00000E-01	1.39781E+01	.788	-.867	-46.824	7.290
2.00000E-01	1.04850E+01	1.507	-1.824	-64.400	8.140
4.00000E-01	3.18315E+00	1.848	-2.351	-122.945	7.821
8.00000E-01	-8.78885E+00	1.950	-2.518	-151.286	5.558
1.00000E+00	-1.01702E+01	1.930	-2.485	-157.918	4.704
2.00000E+00	-1.99585E+01	1.618	-1.990	-173.573	2.808
4.00000E+00	-2.89182E+01	.956	-1.074	173.226	2.889
8.00000E+00	-3.07023E+01	.526	-.559	157.183	4.541
1.00000E+01	-3.18247E+01	.586	-.606	150.981	5.110
2.00000E+01	-3.49425E+01	1.019	-1.155	130.089	5.556
4.00000E+01	-3.98411E+01	1.392	-1.658	112.482	3.926

THE ARGUMENTS AND TOLERANCES ARE:

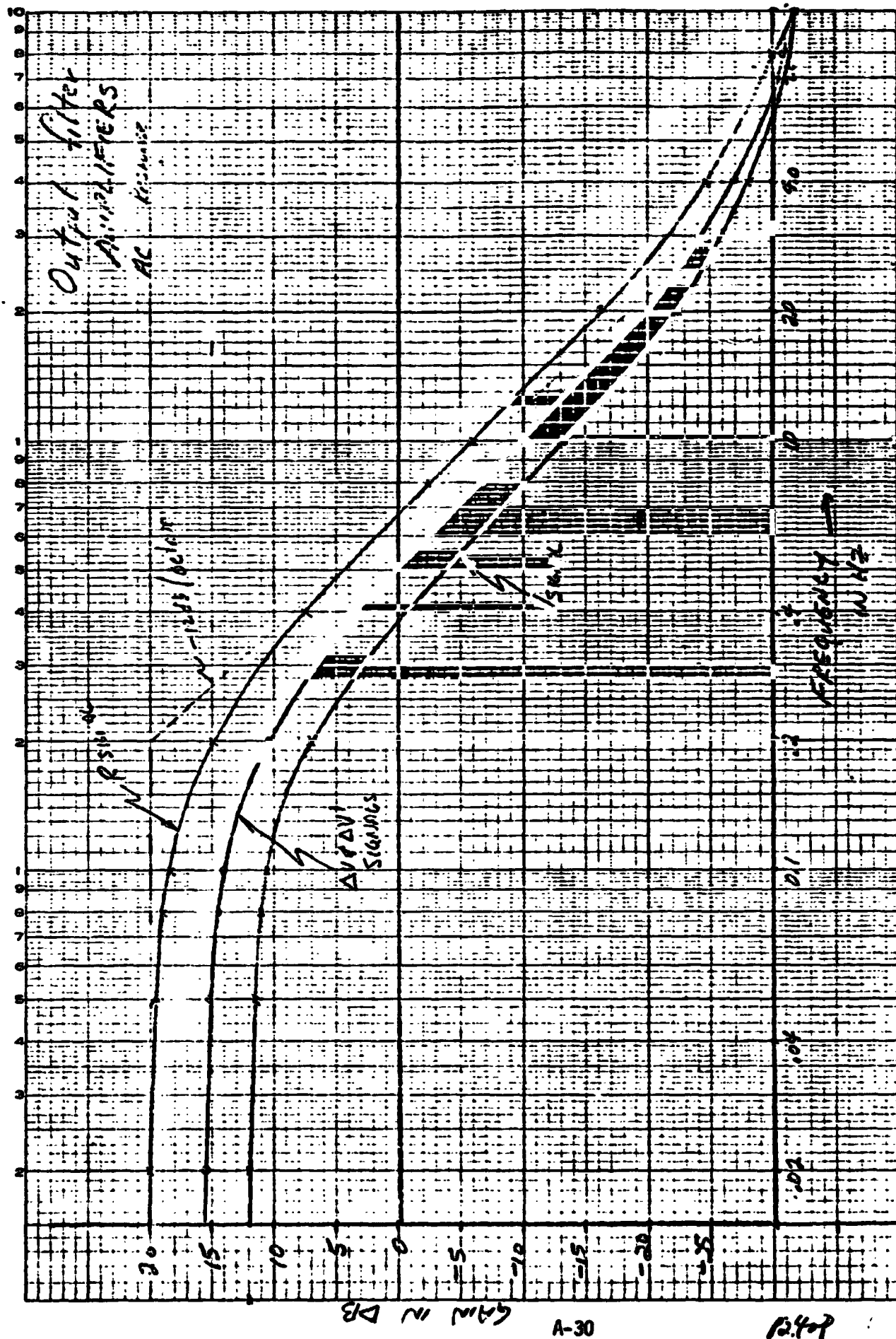
R0	R0	300000	20	R5	R5	2000	2
R1	R1	357000	2	R6	R6	10000	2
C2	R2	.2E-05	20	C7	R7	.1E-05	20
R3	R3	357000	2	T1	R8	.159E+00	20
C4	R4	.2E-05	20				

PROGRAM: OUTPUT FILTER AMPLIFIER
07/22/75. 07.49.41.

DC GAIN = 15.53db or 6.2
See graph for Response Plot

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ORIGINATOR 1000	DATE	TITLE Output Filter Amps	ENGINEERING SKETCH
			TRW
			ONE SPACE PAPER - REDUCED GRADE - CALIFORNIA
MJO		ΔV , $\Delta V'$ AMPLIFIERS	SK
		A-29	SHEET - 3 OF



OUTPUT FILTER AMPLIFIERS

DC offset

$$LM109A \quad E_{os} = \pm 5mV \pm 5\mu V/^{\circ}C = \pm 5mV + .15mV / \pm 33^{\circ}C$$

$$Bias \text{ Current} = 3nA \text{ max / over temp} = \pm 65mV$$

$$\text{offset Current} = 0.4nA$$

Here input resistances are matched
& Ceramic Cap leakage can be ignored

$$\begin{aligned} \therefore E_{os} (\text{Total}) &= \pm E_{os} \pm I_{os} \times R \\ @input &= \pm 0.65mV \pm .4 \times 10^{-9} \times .707 \times 10^6 \\ &= \pm 0.65mV \pm .31mV = \pm .91mV \end{aligned}$$

GIVEN VARIOUS GAINS, THE MAX. DC offset
AND offset VARIATION IS

AMPLIFIER	GAIN	MAX DC output offset	MAX VARIATION IN output offset
R	10	9.1mV	4.6mV
V	4	3.64mV	1.84mV
ΔV	6	5.5mV	2.8mV
$\Delta V'$	6	5.5mV	2.8mV

ORIGINATOR DJE	DATE	TITLE Output Filter AMPLIFIERS (DC offset)	ENGINEERING SKETCH TRW ONE BRIDGE PARK • REDWOOD CITY, CALIFORNIA
MJO			SK SHEET 5 OF

TRIY
SYSTEMS GROUP

PROJECT

SUBJECT

PREPARED BY:

ATTACHMENT

PAGE

DATE

OF

ATTACHMENT B

OVERALL SIGNAL PROCESSING

- AGC LOOP Time Constant
- OUTPUT Scale factors
- ΔV , $\Delta V'$ offsets
- ΔV , V , & R GAIN STABILITY

TRW SYSTEM GROUP		PREPARED BY:	ATTACHMENT	PAGE 1 OF 01
PROJECT MAPS	SUBJECT SIGNAL PROCESSING CIRCUITS	DATE		

AGC LOOP TIME CONSTANT

1) PER FARRENKOPF ANALYSIS, Time Constant

$$T = \frac{\pi}{2 K_1 K_f A_1}$$

where: $K_1 A_1 =$ peak amplitude
of R component @ analog
multiplier input.

$$\text{AND } \frac{2K_f}{\pi} = \text{loop gain in (Volt Sec)}^{-1}$$

2) INPUT SIGNAL

$K_1 A_1$ WAS ASSUMED TO BE 1.0V_{pp} @
SIGNAL PROCESSING INPUT, WITH BUFFER GAIN OF
0.5, $K_1 A_1$ AT MULTIPLIER INPUT IS 0.5V_{pp} OR 0.25V_p.

3) LOOP GAIN

$$= \left(\frac{\text{MULTIPLIER GAIN}}{V/V} \right) \times \left(\frac{\text{DIFF. AMP GAIN}}{V/V} \right) \times \left(\frac{\text{DEMOD GAIN}}{V_{dc}/V_p} \right) \times \left(\frac{\text{INTG GAIN}}{V/V_{sec}} \right) \times \left(\frac{\text{FEEDBACK ATTEN}}{V/V} \right)$$

$$= (M_G \times D.A.G. \times \text{Demod}_G \times \text{Int}_G \times \text{ATT}_G) (\text{Volts}_{peak} \cdot \text{Sec})^{-1}$$

$$= \left(\frac{1}{8} \right) \left(\frac{10V}{V} \right) \left(\frac{1V_{dc}}{V_{peak}} \right) \left(\frac{1}{1.86} \right) \left(\frac{10K}{33.7K} \right)$$

$$= 0.20 (V_p \text{ Sec})^{-1}$$

MULTIPLIER GAIN CAN HAVE INITIAL VALUE
FROM $(1/7)$ TO $(1/9)$ MAKING LOOP GAIN VARY
FROM .23 TO .18 IN INITIAL VALUE.

TRW SYSTEMS CORP.		PREPARED BY: <i>NFE</i>	ATTACHMENT	PAGE 2
PROJECT <i>RRPS</i>	SUBJECT <i>SIGNAL PROCESSING CIRCUITS</i>	DATE		OF

AGC Loop Time Constant Calc.

So Loop Time Constant for $R = 10 \mu p$ is

$$T = \frac{1}{.25 V_p \times \frac{.2}{V_p \text{Sec}}} = 20 \text{ Sec}$$

or for Loop Gain of .18 to .22

$$T = 17.4 \text{ to } 22.2 \text{ Seconds.}$$

① An R Component of $1.5 V_{pp}$, input to Multiplier is $.375 V_{peak}$ so Loop Time Constant is

$$T = \frac{1}{.375 \times .2} = 13.3 \text{ Seconds.}$$

STABILITY of THE Loop Time Constant AT A GIVEN VALUE OF R depends on STABILITY of Loop Gain

RSS: VARIATION IN Loop Gain is

$$\frac{\Delta L.G.}{L.G.} = \left\{ \underbrace{(\pm 1\%)^2}_{\text{multiplier}} + \underbrace{(\pm 1\%)^2}_{\text{b1FP and}} + \underbrace{(\pm .1\%)^2}_{\text{Demod}} + \underbrace{(1.6\%)^2}_{\text{Integ.}} + \underbrace{(1.4\%)^2}_{\text{AGC feedback ATT.}} \right\}^{1/2}$$

$$= \underline{\pm 2.6\% \text{ r.s.s.}}$$

TRW SYSTEM GROUP		PREPARED BY: <i>WFE</i>	ATTACHMENT	PAGE <i>4</i> OF
PROJECT <i>MIAPS</i>	SUBJECT <i>SIGNAL PROCESSING CIRCUITS</i>	DATE		

$\Delta V, \Delta V'$ TOTAL offset ERRORS

Per Demod ANALYSIS demod offset VARIATION = $\pm .9mV$

Per output AMP ANALYSIS

$\Delta V, \Delta V'$ GAIN = 6, MAX offset VARIATION
= $2.8mV$

So TOTAL $\Delta V, \Delta V'$ offset VARIATION, RSS,

$$= \left[(6 \times .9)^2 + (2.8)^2 \right]^{1/2}$$

$$= \pm \underline{6.1mV} \text{ RSS}$$

GAIN STABILITY of $\Delta V, \Delta V'$ CHANNEL

Demod GAIN STABILITY = $\pm .06\%$

ERROR AMP ST. = $\pm .06\%$

DIFF. AMP STABILITY = $\pm 1.1\%$

$$\text{So RSS total} = \pm \underline{1.11\%}$$

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APPENDIX B

DESIGN ANALYSIS REPORT, PYROELECTRIC DETECTOR GAIN CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides the design and analysis documentation for the pyroelectric detector preamplifier and second amplifier gain stages.

2.0 CIRCUIT REQUIREMENTS

Each of 3 pyroelectric detectors (PIN 8D008) shall interface with a preamplifier and 2nd amplifier which have the following characteristics.

2.1 Detector Interface

- Source Load Impedance - $68.1K \pm 1\%$ to - 12V
- Bias Voltage = - 6.0V $\pm 2\%$ from $\leq 500K$ dc impedance

2.2 Preamplifier

The preamplifier shall have a gain characteristic which rises at 6db per octave from 0.32Hz to 160 Hz.

The gain at 39 Hz shall be 248 ± 10 percent. The preamplifier equivalent input noise with the input terminated in 10K ohms shall not exceed 30 NV rms in a 0.2 Hz bandwidth centered at the scene chopping frequency of 25 Hz.

2.3 Second Amplifier

The preamplifier shall be followed by a second gain stage which raises the detector signal level to the ± 5 volt range. This stage shall have its low frequency response at less than 2.5 Hz and its high frequency rolloff at greater than 500 Hz. The gain shall be adjustable by resistor selection and/or potentiometer adjustment from 10 to 40.

3.0 CIRCUIT DESCRIPTION AND ANALYSIS RESULTS

3.1 Preamplifier

A schematic of the preamplifier circuit is shown on page #1 of the attached analysis. It is also shown on sketch schematic SK-MAPS-BB-105.

The circuit consists of a low noise differential FET stage followed by a LM108A operational amplifier. The feedback network around the amplifier then provides the required frequency response.

Pages 1 thru 5 of the attached analysis covers the FET stage biasing and show an adequate phase margin to provide closed loop stability.

Pages 6 and 7 provide a tabulation of the expected closed loop response. Page 15 is a plot of measured preamplifier response.

Analysis pages 9 thru 12 provide a simplified calculation of the preamplifier equivalent input noise and presents test data which shows fairly close agreement. In all cases the preamplifier noise contribution is significantly less than that of the detector.

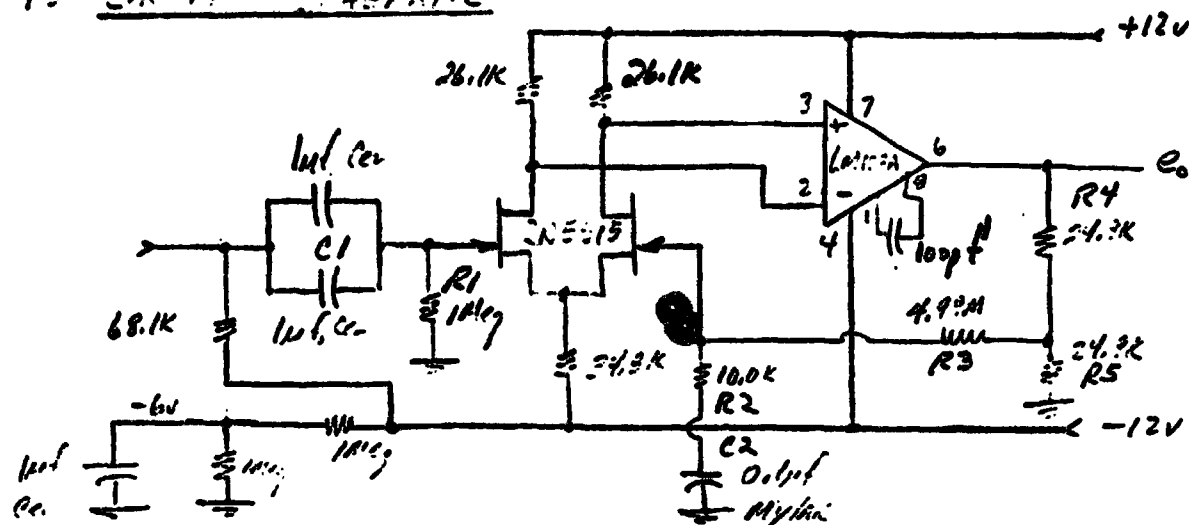
Pages 13 and 14 of the analysis compute the ratio of the preamplifier gains at 23.5 Hz and 39 Hz (old operating frequencies) as a function of component variations. For the component tolerances used, the rss variation in the gain ratio was 0.1 percent.

3.2 Second Amplifier

The second amplifier consists of an integrated circuit operational amplifier, AR2(HA2-2700) and its feedback network components as shown in sketch schematic SK MAPS-BB-105.

Attached analysis pages 16 and 17 cover the performance of the amplifier. Potentiometer R7 is used to set the overall gain to match a particular detector responsivity.

1.0 CIRCUIT SCHEMATIC



2.0 FET INPUT STAGE

• FET BIASING

$$\text{FET DRAIN CURRENT} = I_D = \frac{1}{2} \left(\frac{12 + V_{GS}}{R_D} \right) = \frac{1}{2} \left(\frac{12 + 2}{34.8K} \right)$$

$$\approx 200\mu A$$

$$\therefore V_D (\text{Each FET}) = 12 - .2mA \times 26.1K = \underline{6.8V}$$

$$\therefore V_{DS} \geq \underline{4.8V}$$

• FET STAGE GAIN

$$GAIN \approx g_m R_L \approx 500\mu mhos \times 26.1K = 13$$

• FET STAGE BREAK FREQUENCY

$$C_{iss} = 5pF @ 20V V_{GD}$$

$$C_{gd} \approx C_{iss} \times \sqrt[3]{\frac{V_{DSS}}{V_{GS}}} + C_{P, \text{MOSFET}} = 5pF \sqrt[3]{\frac{20}{5}} + 1.5$$

$$\approx 8pF$$

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PROJECT A1.425	SUBJECT PYRO-DETECTOR PREAMPLIFIER	DATE 5/24/75		

2. FET INPUT STAGE (CONTINUED)

• FET STAGE BREAK FREQ CONT.

$$f_{B1011} \approx \frac{1}{2\pi C_{gs} 2R_D \cdot G} = \frac{.159}{8pf \times 26.1K \times 2 \times 15}$$

$$\approx 25.5 Kc$$

$$\therefore T_1 = 6.3 \mu sec$$

and Transfer function of FET Stage

$$K_1 = \frac{A_1}{T_1 s + 1} \quad \text{where we Assume } A_1 = 15 \pm 30\%$$

$$T_1 = 6.3 \mu sec \pm 50\%$$

3. LM103A STAGE

$$\text{with } C_{PIN1-8} = 30pf, \quad f_{unity\ gain} \approx \underline{750 KHz}$$

$$\therefore \text{with } C_{1-8} = 100pf, \quad f_{u2} = \underline{225 Kc}$$

$$\text{FOR DC GAIN} \approx 3 \times 10^5 = 109.54 db$$

\therefore LM100 STAGE Transfer function is Assumed to

be

$$K_2 = \frac{A_2}{T_2 s + 1} \quad \text{where } A_2 = 3 \times 10^5 \pm 30\%$$

$$f_{BREAK} = 0.75 Hz$$

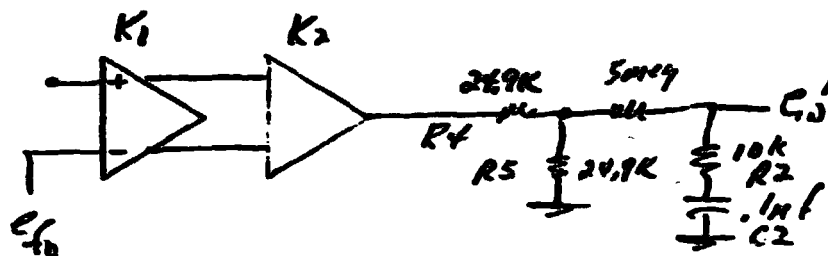
$$T_2 = .212 sec \pm 30\%$$

TRW		PREPARED BY: <i>[Signature]</i>	ATTACHMENT	PAGE 3 OF 00
PROJECT MARS	SUBJECT HYPO- DETECTOR PREAMPLIFIER	DATE		

4.0 AMPLIFIER STABILITY (GAIN/PHASE MARGIN)

TO ESTABLISH CLOSED LOOP FREQ STABILITY,
WE CONSIDER OPEN LOOP GAIN PLOT AS FOLLOWS:

Loop Gain:



∴ Loop Gain is

$$= K_1 K_2 \times \left(\frac{R_5}{R_4 + R_5} \right) \left(\frac{Z_2}{R_4 \| R_5 + R_3 + Z_2} \right)$$

where $Z_2 = (R_2 + \frac{1}{sC_2})$

DATA INPUT TO RSSWC1 PROGRAM IS THEN:
(VARIABLE ASSIGNMENTS ARE SHOWN IN PRINTOUT)

```

500 FOR F = .1, 1, 10, 20, 40, 100, 200, 400, 1E3, 2E3, 4E3, 1E4, 2E4, 5E4, 1E5, 2E5
2000 DATA 15, 6.2E-6, 3E5, .212, 24900, 24900
2001 DATA 5E6, 1E4, .1E-6, 1E6, 2E-6
2100 DATA 30, 50, 30, 30, 2, 2
2101 DATA 2, 2, 5, 2, 20
2200 DATA A1, T1, A2, T2, P4, P5
2201 DATA R3, R2, C2, F1, C1
2300 DATA "HYPO-PREAMP RESPONSE"
3000 F1=A1*CNFLX(1, A1+W)
3010 F2=A2*CNFLX(1, A2+W)
3020 Z1=(A4+R5)/(A4+R5)
3030 Z2=CNFLX(A2, -1, 1, W)
3040 Z3=CNFLX(0, W, B0+R2, CNFLX(1, W, B0+R2)
3040 B=(A5+R5+R4)/(1+Z2+Z3+Z1)
3050 F1=F1*2*B
3060 F1=F1

```

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PROJECT: *MAPS* SUBJECT: *PYFO-DETECTOR PREAMPLIFIER* DATE: *5/29/75*

4 AMPLIFIER Stability Plot.

Resultant Computer Res. (GAIN IN V/V)

FREQ	GAIN (V/V)	TOL. (%)	PHASE	TOL. DEG.
1.00000E-01	2.12691E+06	42.456	-25.0657	2.417
1.00000E+00	4.08074E+05	46.840	-125.1628	8.296
1.00000E+01	5.34550E+05	52.158	-170.3187	1.289
2.00000E+01	1.34758E+03	52.225	-169.3248	.729
4.00000E+01	3.44875E+02	52.223	-164.4524	.780
1.00000E+02	6.32131E+01	52.143	-147.4696	1.392
2.00000E+02	2.14698E+01	52.067	-128.6524	1.517
4.00000E+02	9.04796E+00	52.350	-112.4368	1.148
1.00000E+03	3.40293E+00	52.054	-101.2128	1.213
2.00000E+03	1.68181E+00	52.056	-98.9743	2.232
4.00000E+03	8.31429E-01	52.069	-101.1200	4.360
1.00000E+04	3.13420E-01	52.471	-112.1895	9.690
2.00000E+04	1.32655E-01	55.376	-128.3756	13.889
5.00000E+04	3.07213E-02	65.366	-153.0051	11.639
1.00000E+05	8.36224E-03	70.070	-165.6935	6.899
2.00000E+05	2.14078E-03	71.616	-172.7313	3.617

THE ARGUMENTS AND TOLERANCES ARE:

A1	A0	15	30	R3	A6	5000000	2
T1	A1	.62E-05	50	F2	A7	10000	2
A2	A2	300000	30	C2	A8	.1E-06	5
T2	A3	.212E+00	30	P1	A9	1000000	2
R4	A4	24900	2	C1	B0	.2E-05	20
R5	A5	24900	2				

PROGRAM: PYFO-FPEAMP RESPONSE
05/30/75. 09.16.23.

*From The Above Data we see
Phase margin: NOMINALLY GREATER THAN 79°
INSURING ADEQUATE CLOSED LOOP STABILITY.*

TRW
DEFENSE GROUP

PREPARED BY: *[Signature]* ATTACHMENT
DATE: 5/29/75 PAGE 5 OF

PROJECT: MAPS SUBJECT: PYRO DETECTOR FREQUENCY

4. AMPLIFIER STABILITY (CONTINUED) RESULTANT COMPUTER RUN, (GAIN IN DB)

200 HZ MIN 1000

FREQ	GAIN DB	+TOL	-TOL DB	PHASE	TOL DEG
1.00000E+01	1.26555E+02	3.974	-4.830	-25.066	2.417
1.00000E+02	1.12215E+02	3.937	-5.438	-125.163	2.298
1.00000E+03	7.45598E+01	3.946	-6.404	-170.319	1.283
2.00000E+03	6.25911E+01	3.650	-6.416	-169.825	.729
4.00000E+03	5.97532E+01	3.650	-6.416	-164.452	.781
1.00000E+02	3.50161E+01	3.645	-6.401	-147.470	1.398
2.00000E+02	2.66446E+01	3.641	-6.387	-128.652	1.517
4.00000E+02	1.91310E+01	3.640	-6.384	-112.437	1.148
1.00000E+03	1.05371E+01	3.640	-6.385	-101.213	1.211
2.00000E+03	4.51556E+00	3.640	-6.385	-98.974	2.238
4.00000E+03	-1.60350E+00	3.641	-6.388	-101.120	4.360
1.00000E+04	-1.00775E+01	3.664	-6.461	-112.189	9.896
2.00000E+04	-1.75455E+01	3.828	-7.003	-128.376	13.985
5.00000E+04	-3.02512E+01	4.370	-9.215	-153.005	11.639
1.00000E+05	-4.15535E+01	4.613	-10.478	-165.694	6.899
2.00000E+05	-5.33886E+01	4.691	-10.939	-172.731	3.617

THE ARGUMENTS AND TOLERANCES ARE:

A1	A0	15	30	R3	A5	5000000	2
T1	A1	.62E-05	50	P2	A7	10000	2
A2	A2	300000	30	C2	A3	.1E-06	5
T2	A3	.212E+00	30	P1	A9	1000000	2
P4	A4	24900	2	C1	B0	.2E-05	20
P5	A5	24900	2				

PROGRAM: PYRO-FREQUENCY RESPONSE
05-30-75. 08.15.19.

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PROJECT
MARS

SUBJECT
PYRO-DETECTOR PREAMPLIFIER

PREPARED BY: FSE
DATE: 5/29/75

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OF

5. CLOSED LOOP GAIN RESPONSE:

USING THE OPEN-LOOP GAIN EQUATIONS:
THE CLOSED LOOP RESPONSE IS: (including input Capable network)

$$G = \left(\frac{1}{\beta} \right) \left(\frac{K_1 K_2 \beta}{1 + K_1 K_2 \beta} \right) \times K_3$$

where:

$$\beta = \left(\frac{R_5}{R_4 + R_5} \right) \left(\frac{z_2}{R_4 R_5 + R_3 + z_2} \right)$$

where $z_2 = R_2 + \frac{1}{sC_2}$

$$K_1 = \frac{A_1}{T_1 s + 1}, \quad K_2 = \frac{A_2}{T_2 s + 1}, \quad K_3 = \left(\frac{S R C_1}{S R C_1 + 1} \right)$$

RSWEE Computer input DATA CHANGES ARE THEN:

1 2300 DATA "PYRO-FREAMP CLOSED LOOP RESPONSE"
3 3200 X= Z3*(1/B)*(X1/(X1+1))

CLOSED LOOP GAIN RUN IN DB:

FREQ	GAIN(DB)	+TOL.	-TOL.(DB)	PHASE	TOL(DEG)
1.00000E-01	4.30233E+00	.663	-.718	55.990	5.680
1.00000E+00	1.63905E+01	.431	-.454	76.607	1.260
1.00000E+01	3.59911E+01	.469	-.495	85.044	.151
2.00000E+01	4.19624E+01	.465	-.491	82.150	.344
4.00000E+01	4.78922E+01	.450	-.474	75.508	.713
1.00000E+02	5.46732E+01	.380	-.397	57.228	1.439
2.00000E+02	5.81585E+01	.317	-.329	36.300	1.945
4.00000E+02	5.97259E+01	.306	-.318	15.575	3.459
1.00000E+03	6.00533E+01	.299	-.310	-7.970	8.851
2.00000E+03	5.93369E+01	.985	-1.112	-23.374	15.007
4.00000E+03	5.70535E+01	2.417	-3.360	-54.669	18.012
1.00000E+04	5.06078E+01	3.704	-6.592	-93.059	15.037
2.00000E+04	4.31842E+01	4.003	-7.647	-121.455	16.664
5.00000E+04	3.00279E+01	4.452	-9.617	-152.002	12.306
1.00000E+05	1.85560E+01	4.637	-10.619	-165.463	7.012
2.00000E+05	6.66881E+00	4.695	-10.964	-172.670	3.590



PROJECT

SUBJECT

PREPARED BY:

ATTACHMENT

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1.000

A/PRI- DETECTOR

FREAMPLIFIER

DATE

5/2/75

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5. CLOSED LOOP RESPONSE
RSS DATA IN V/V.

ALL ANALYSIS:

FREQ	GAIN(V/V)	TOL.(%)	PHASE	TOL(DEG)
1.00000E-01	1.64103E+00	7.935	55.3500	5.680
1.00000E+00	6.59972E+00	5.093	76.6070	1.260
1.00000E+01	6.36310E+01	5.543	85.0438	.151
2.00000E+01	1.25349E+02	5.498	82.1503	.344
4.00000E+01	2.45535E+02	5.316	75.5076	.713
1.00000E+02	5.41613E+02	4.473	57.2281	1.439
2.00000E+02	8.08955E+02	3.714	36.3004	1.945
4.00000E+02	9.68932E+02	3.591	15.5751	3.459
1.00000E+03	1.00615E+03	3.507	-7.9702	6.851
2.00000E+03	9.26501E+02	12.012	-22.3744	15.007
4.00000E+03	7.12815E+02	32.060	-54.5295	18.018
1.00000E+04	3.39149E+02	53.184	-93.0589	15.037
2.00000E+04	1.44281E+02	58.540	-121.4546	16.664
5.00000E+04	3.17244E+01	66.953	-152.0015	12.306
1.00000E+05	8.46838E+00	70.554	-165.4831	7.012
2.00000E+05	2.15497E+00	71.698	-172.6702	3.632

THE ARGUMENTS AND TOLERANCES ARE:

A1	A0	15	30	P3	A6	5000000	2
T1	A1	.62E-05	50	R2	A7	10000	2
A2	A2	300000	30	C2	A8	.1E-06	5
T2	A3	.212E+00	30	R1	A9	1000000	2
P4	A4	24900	2	C1	B0	.2E-05	20
P5	A5	24900	2				

PROGRAM: PYRD-PPEAMP CLOSED LOOP RESPONSE
05/30/75. 08.22.28.

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TRW TECHNICAL RECORD		PREPARED BY: <u>NGE</u>	ATTACHMENT	PAGE 1 OF
PROJECT V. L. P. 5	SUBJECT P. L. - DETECTOR PRE-AMPLIFIER	DATE 5/1/75		

6. OUTPUT DC & P.W.

• AMPLIFIER DC GAIN = $1 + \frac{R_5 + R_6}{R_5} = \underline{3}$

• INPUT offset Voltage

$$\begin{aligned} E_{os} (\text{fet pair}) &= 5\text{mV initial} \\ &+ 5\mu\text{V}/^\circ\text{C} \times 20^\circ\text{C} = 5\text{mV} \pm 1\text{mV} \\ &= 5.1\text{mV TOTAL} \end{aligned}$$

$$\begin{aligned} i_{bias} \text{ of fet pair} &= 100\mu\text{A} @ 25^\circ\text{C} \\ &\approx 600\mu\text{A} @ 50^\circ\text{C} \end{aligned}$$

$$S_o E_{os} \Big|_{\text{due to } i_b} = .625 \times 5\text{mV} = 3\text{mV}$$

$$\therefore \text{TOTAL input offset} = \pm 0.1\text{mV}$$

$$\text{and @ output} = 3 \times 0.1 = \pm \underline{34\mu\text{V}}$$

7) PREAMP EQUIVALENT INPUT NOISE @ 20Hz

a) NOISE SOURCES

1) \bar{E}_n of each Fet $\leq 30\text{mV}/\sqrt{\text{Hz}} @ 10\text{Hz}$
 ASSUME $\bar{E}_n = 20\text{mV}/\sqrt{\text{Hz}} @ 20\text{Hz}$
 (1/2 effect)

2) $i_g(\text{fet}) \leq 600\mu\text{A} @ 50^\circ\text{C}$
 $\therefore \bar{i}_s = (2q \bar{i}_g)^{1/2} = 1.4 \times 10^{-14} \text{ AMP}/\sqrt{\text{Hz}}$

3) JOHNSON NOISE of INPUT RESISTANCE
 AT INVERTING & NON-INVERTING
 INPUTS.

PROJECT		PREPARED BY:	ATTACHMENT	PAGE
MPS		R. J. E.		OF
SUBJECT		DATE		
FPGA-DESIGN PROJECT				

7. Calculate the total input noise

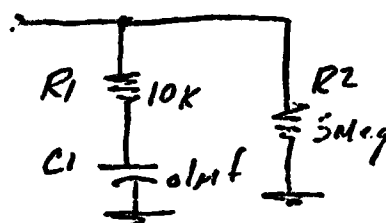
B) So Total ^{ER} input noise is:

$$\begin{aligned} \overline{e}_w^2 = & \overline{e}_{n_{fet}}^2 (A.V.) + \overline{e}_{n_{fet}}^2 (mV) + \overline{I}_{n_{fet}}^2 \times |Z_w|^2_{mV} \\ & + \overline{I}_{n_{fet}}^2 \times |Z_w|^2_{mV} + \overline{e}_{n_{fet}}^2 \text{ by Resistance Noise @ } 1mV + \overline{e}_{n_{fet}}^2 \text{ by } \dots \end{aligned}$$

c) $Z_w (non-inv) = 10K\Omega$ (Detector Z. BASHALL)

d) $Z_w (inverting) =$

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$$= \frac{R_2(1+j\omega C_1 R_1)}{1+j\omega(R_1+R_2)C_1} = \frac{5 \times 10^6 (1+j 2\pi \times 20 \times 10^3 \times 10^{-6} \times 10^4)}{(1+j 2\pi \times 20 \times 5.01 \times 10^6 \times 0.1)}$$

$$|Z| = 80K @ 20KHz$$

So I_n of fet is developed across 80K

e) Johnson Noise of R_1 & R_2 = ?

Johnson Noise of R_1 All Seen at input

Johnson Noise of R_2 Shunted by R_1 & C_1

can model as current noise $\frac{4KT\Delta f}{R_2}$

Applied To The 80K impedance

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SUBJECT



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7) Noise Calculation Cont.

Summary of Mean Sq Noise Sources:

a) $\overline{e_n^2}_{fet} = (20 \text{ nV}/\sqrt{\text{Hz}})^2$ for both NZ & INV inputs @ 20Hz

b) $\overline{I_{n_{fet}}^2} \times 80k = (1.4 \times 10^{-14} \text{ A}/\sqrt{\text{Hz}})^2 (8 \times 10^4)^2 = (1.12 \text{ nV}/\sqrt{\text{Hz}})^2$

c) $\overline{I_{n_{fet}}^2} \times 10k = (1.4 \times 10^{-14} \text{ A}/\sqrt{\text{Hz}})^2 (10^4)^2 = (0.14 \text{ nV}/\sqrt{\text{Hz}})^2$

d) $\overline{e_{n_{R1}}^2} = 4KTR \text{ V}^2/\text{Hz} = (13.4 \text{ nV}/\sqrt{\text{Hz}})^2$
10K @ Non-INV. input.

e) $\overline{e_{n_{R1}}^2} = (13.4 \text{ nV}/\sqrt{\text{Hz}})^2$
10K @ INV input

f) $\overline{e_{n_{R2}}^2}_{\text{as sh. res}} = \left(\frac{4KT\Delta f}{R} \right) \times (180K)^2$
 $= \frac{1.27 \times 10^{-20}}{5 \times 10^6} \times 64 \times 10^6 = 16.26 \times 10^{-10} = (4 \text{ nV}/\sqrt{\text{Hz}})^2$

Therefore Total Noise @ 20Hz

$$\overline{e_T} = \left\{ (20)^2 + (20)^2 + (1.12)^2 + (0.14)^2 + (13.4)^2 + (13.4)^2 + (4)^2 \right\}^{1/2} \text{ nV}/\sqrt{\text{Hz}}$$

= 34.3 nV/ $\sqrt{\text{Hz}}$ Noise density @ 20Hz

Measured 20Hz Noise with HP 302
WAVE ANALYZER

$\approx 30 \text{ nV}/\sqrt{\text{Hz}}$

TRW
SYSTEMS GROUP

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DATE

11/1/75

1.1a-Detector 12-000-01-10

6/5/75

7. Noise data — MEASURED WITH HP 302 WAVE
ANALYZER (DISCARDING 60Hz NOISE, TH)
MEASURED NOISE PERFORMANCE WAS AS FOLLOWS WITH BARNES:

FREQ	GAIN	OUTPUT NOISE WITH HP 302	EQ INPUT NOISE (60Hz BW)	EQ INPUT NOISE (1Hz BW)	BB Detect:	
					OUTPUT NOISE	EQ INPUT NOISE
20Hz	2660	0.2mV	7.5×10^{-8} V rms	31nV/Hz	2mV	306 nV/Hz
40Hz	5281	0.35mV	6.6×10^{-8} V rms	27nV/Hz	2mV	155 nV/Hz
100Hz	11416	0.6mV	5.26×10^{-8}	21.5nV/Hz	2mV	71.5 nV/Hz
200Hz	16191	0.7mV	4.32×10^{-8}	17.7nV/Hz	1.8mV	45.4 nV/Hz
400Hz	16792	0.7mV	4.17×10^{-8}	17.0nV/Hz	1.5mV	36.5 nV/Hz

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PUMP-DETECTOR PREAMPLIFIER

DATE

8) RATIO of GAINS at Ref. freq & Scene frequency
Scene freq = $f_1 = 23.5 \text{ kHz}$
Ref Balance freq = $f_2 = 1.67 \times f_1 = 39 \text{ kHz}$

∴ TAKING THE CLOSED LOOP RESPONSE EQUATIONS
of PG & SOLVING CO f_1 & f_2 AND FINDING THE
GAIN RATIO WITH RESUME PROGRAM WE HAVE:

REVISED PROGRAM:

C LIST,PAMP1

```
500 FOR F=5 TO 40 BY5
2000 DATA 15.6,2E-6,3E5,.212,24900,24900
2001 DATA 5E6,1E4,.1E-6,1E6,2E-6
2100 DATA 30,50,30,30,2,2
2101 DATA 2,2,5,2,20
2200 DATA A1,T1,A2,T2,A4,P5
2201 DATA R3,R2,C2,P1,C1
2300 DATA 'PYPC-PREAMP GAIN RATIO'
3000 K1=A0/CMPLX(C1,A1+0)
3010 K2=A2/CMPLX(C1,A3+0)
3020 Z1=(A4+A5)/(A4+A5)
3030 Z2=CMPLX(A7,-1/(W*A8))
3035 Z3=CMPLX(0,W*B0*A9)/CMPLX(1,W*B0*A9)
3040 B=(A5/(A5+A4))*(Z2/(Z2+A6+Z1))
3050 X1=1+Z2*B
3100 X2=Z3*(1/B)*(X1/(X1+1))
3105 K3=A0/CMPLX(C1,A1+0*1.67)
3110 K4=A2/CMPLX(C1,A3+0*1.67)
3120 Z4=CMPLX(A7,-1/(1.67*W*A8))
3125 Z5=CMPLX(0,W*B0*A9*1.67)/CMPLX(1,1.67*W*B0*A9)
3130 A=(A5/(A5+A4))*(Z4/(Z4+A6+Z1))
3140 X3=K3*K4*A
3150 X4=Z5*(1/A)*(X3/(X3+1))
3200 Y=X4/X2
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TRW SYSTEMS GROUP		PREPARED BY: <i>12-68</i>	ATTACHMENT	PAGE <i>14</i> OF
PROJECT <i>AMP</i>	SUBJECT <i>P120-detector P. amplifier</i>	DATE <i>6/13/75</i>		

8) GAIN RATIO

USING $\pm 1\%$ RESISTANCE & $\pm 5\%$ CAPACITOR TOLERANCE,
Results ARE

TABLE ANALYSIS

SCENE FREQ	$\frac{G(f_2)}{G(f_1)}$ GAIN(V)	TOL (%)	PHASE	TOL (DEG)
5.00000E+00	1.66666E+00	.007	-1.11144444444444	.110
1.00000E+01	1.66423E+00	.026	-1.8529	.103
1.50000E+01	1.65798E+00	.059	-3.2061	.126
2.00000E+01	1.64919E+00	.104	-4.4369	.153
2.50000E+01	1.63818E+00	.158	-5.5907	.179
3.00000E+01	1.62521E+00	.219	-6.6780	.202
3.50000E+01	1.61057E+00	.287	-7.7004	.222
4.00000E+01	1.59452E+00	.357	-8.6583	.240

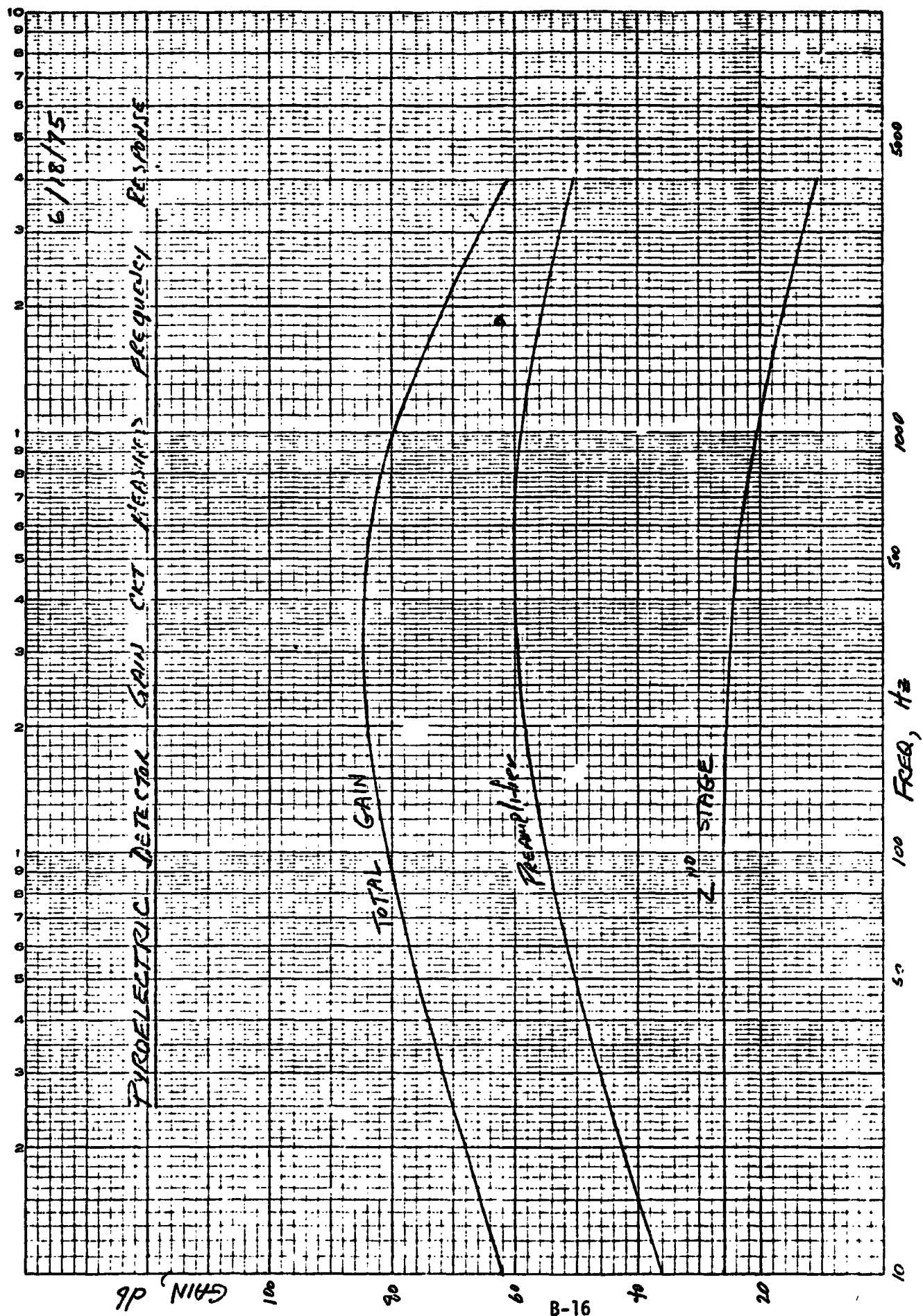
THE ARGUMENTS AND TOLERANCES ARE:

A1	A0	15	30	P3	A6	5000000	1
T1	A1	.62E-05	50	R2	A7	10000	1
A2	A2	300000	30	C2	A8	.1E-06	3
T2	A3	.212E+00	30	R1	A9	1000000	1
F4	A4	24900	2	C1	B0	.2E-05	20
F5	A5	24900	2				

PROGRAM: PYFO-PREAMP GAIN RATIO
05-13-75. 08.23.29.

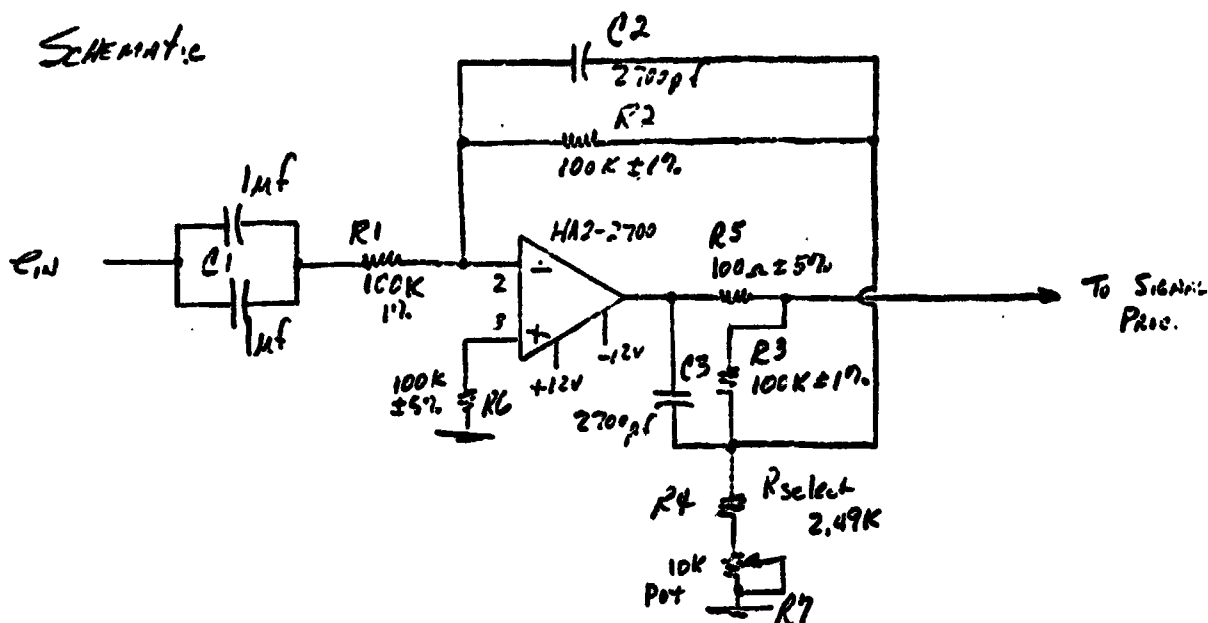
So CHANGE IN GAIN RATIO (FS) IS
 $\approx 0.1\%$ WITH COMPONENT VALUE TOLERANCES
Listed.

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1.11-
F1110-DETECTION 2ND Amplifier

SCHEMATIC



1) INPUT Coupling network 3db freq.

$$f_c = \frac{0.159}{2 \times 10^{-6} \times 10^5} = 0.8 \text{ Hz}, \left(\begin{array}{l} \text{MIN input} \\ \text{freq} = 25 \text{ Hz} \end{array} \right)$$

2) MID BAND GAIN with $R_4 = 2.49 \text{ K}$
 $R_7 = 10 \text{ K Pot}$

$$G = \left(\frac{R_2}{R_1} \right) \left(1 + \frac{R_3}{R_2 \parallel (R_4 + R_7)} \right)$$

AND $R_4 + R_7 = 2.49 \text{ K min}, 7.49 \text{ K nom}, 12.49 \text{ K max}$

$\therefore R_2 \parallel (R_4 + R_7) = 2.43 \text{ K min}, 6.97 \text{ K nom}, 11.1 \text{ K max}$

AND THUS GAIN RANGE IS

$$\left. \begin{array}{l} G_{\text{min}} = 10.1 \\ G_{\text{nom}} = 15.3 \\ G_{\text{max}} = 42.1 \end{array} \right\} \text{per Pot adjustment}$$

TRW SYSTEMS GROUP		PREPARED BY: MTE	ATTACHMENT	PAGE 17 OF
PROJECT MIPS	SUBJECT Pyro-detection and Amplifier	DATE		

3) GAIN STABILITY -

AT THESE LOW GAINS, GAIN STABILITY IS THAT OF FEEDBACK NETWORK COMPONENTS.

ie $4 \pm 1\%$ RESISTORS & $1 - 3\%$ FOT

So RSS GAIN STABILITY OVER ENVIRONMENT

$$= \sqrt{4(1\%)^2 + (3\%)^2} = \sqrt{13} = \pm 3.6\%$$

4) HIGH frequency Roll off

Set by $R_2 C_2$ AND $R_3 C_3$ TIME CONSTANTS

$$f_{HIGH} = \frac{0.159}{2700 \times 10^{-12} \times 10^5} = \frac{1590 \times 10^{-4}}{2700 \times 10^{-4}} = \underline{\underline{589 Hz}}$$

5) CABLE CAPACITY LOADING

100 Ω RESISTOR R_5 EFFECTIVELY DECOUPLES LOAD CABLE CAPACITY AT HIGH FREQUENCY ASSUMING ONLY UNITY FEEDBACK @ HI FREQUENCIES

APPENDIX C

DESIGN ANALYSIS REPORT, LEAD SELENIDE DETECTOR GAIN CIRCUITS FOR THE MAPS BREADBOARD

1.0 SCOPE

This report provides the design and analysis documentation for the cooled lead selenide detector preamplifier and 2nd amplifier gain stages.

2.0 Circuit Requirements

Each of 3 lead selenide detectors (FIN 8D007) shall interface with a preamplifier and second amplifier gain stage having the following characteristics.

2.1 Detector Interface

The preamplifier shall be a.c. coupled to a detector which is biased from a 100 volt bias and is terminated in a 1 megohm load resistance.

2.2 Preamplifier

The preamplifier shall provide a constant gain of $50 \pm 5\%$ over the frequency range of 10 Hz to 3 KHz.

The equivalent input noise shall not exceed 56 nanovolts rms in a 0.2 Hz bandwidth centered at the scene chopping frequency of 177 Hz.

2.3 Second Amplifier

The preamplifier shall be followed by a second gain stage which raises the detector signal level to the ± 5 volt range. This stage shall have its low frequency response at less than 10 Hz and its high frequency rolloff at greater than 5 KHz. The gain shall be adjustable by resistor selection and/or potentiometer adjustment from 10 to 20.

3.0 CIRCUIT DESCRIPTION AND ANALYSIS

3.1 Preamplifier

A schematic of the preamplifier is shown on sketch schematic SK-MAPS-BB-105.

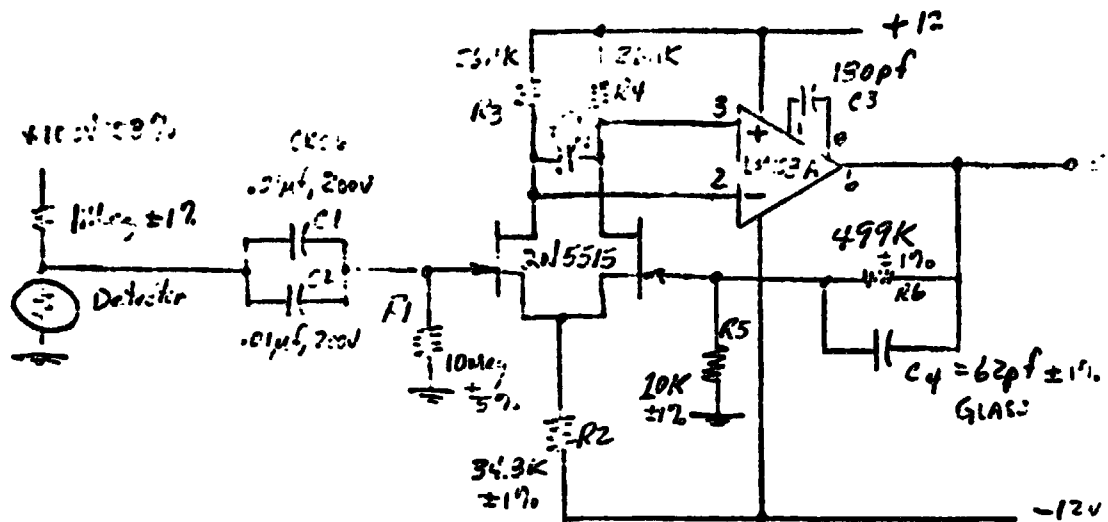
The circuit consists of a low noise differential FET stage followed by a LM108 A operational amplifier.

Pages 1 thru 8 of the attached analysis covers the preamplifier performance. Adequate biasing, closed loop stability and noise performance is shown.

3.2 Second Amplifier

The second amplifier consists of a HA-2-2700 IC operational amplifier and the gain control feedback network. The key performance parameters are given on Page 9 of the attached analysis.

TRV SYSTEMS GROUP		PREPARED BY: DK	ATTACHMENT	PAGE 1
PROJECT ADP-1	SUBJECT Gate Detector, Input Net.	DATE		OF



1) INPUT COUPLING NETWORK

$$Z_{in} = 80 \text{ meq}$$

$$f_c = \frac{159 \times 10^{-3}}{.02 \times 10^{-6} \times \left(\frac{10 \times 20}{90} \right) \times 10^6} = 0.894 \text{ Hz}$$

Minimum Coupling
 freq = 171.5 Hz

2) FET BIASING


$$\text{FET DRAIN CURRENT} = I_D = \frac{1}{2} \left(\frac{12 + V_{gs}}{R_D} \right)$$

$$= \frac{1}{2} \left(\frac{12 + 2}{34.3 \text{ K}} \right) = 0.2 \text{ ma}$$

$$\therefore V_D = +12V - I_D R_D$$

$$= +12V - .2 \text{ ma} \times 26.1 \text{ K} = 6.8V$$

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TRW DEFENSE GROUP		PREPARED BY: 	ATTACHMENT	PAGE 11
PROJECT MAPS	SUBJECT Pulse Detector Preamp Circuit	DATE		OF

3) AMPLIFIER GAIN

$$= \left(1 + \frac{R_5}{R_5}\right) = \left(1 + \frac{491K}{10K}\right) = \underline{50.1}$$

4) Roll-off

$$f_c = \frac{.159}{.491 \times 10^6 \times 62pF} = \underline{5.14Kc}$$

HIGHEST CHOPPING
 $f_{CH} = 265Hz$

5) EQUIVALENT INPUT offset VOLTAGE

E_{os} of fet PAK = 5mV initial
 $+ 5\mu V/^{\circ}C \times \pm 25^{\circ}C = \pm 0.1mV$

I_b of fet PAK = 100pA @ 25°C
 $\approx 600pA @ 50^{\circ}C$

$\therefore E_{os}|_{\text{due to } I_b} = .6nA \times 10M\Omega = 6mV$

So TOTAL DC offset = $\pm 11.1mV$ w/c

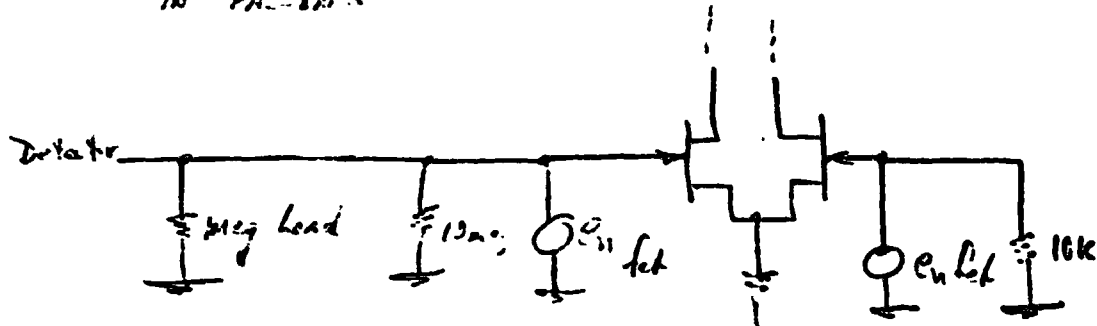
$E_{OUTPUT} = \pm 11.1mV \times 51 = \pm 566mV = \pm .6V_{DC}$

MAXIMUM SIGNAL SWING @ Preamp output

$= \frac{\pm 5V}{2.5 \text{ (minimum gain)}} = \frac{\pm 5V}{2.5} = \pm 2V$

So $\pm 9V$ DYNAMIC RANGE IS MORE THAN ADEQUATE.

b) EQUIVALENT INPUT NOISE
IN PACE 100



NOISE SOURCES

a) Fet $\bar{e}_n = 10 \text{ nV}/\sqrt{\text{Hz}}$ @ $\geq 100 \text{ kHz}$ per Data Sheet

b) $\bar{I}_G \leq 600 \text{ pA MAX @ } 50^\circ \text{C}$

$$\therefore \bar{i}_s = (2q\bar{I}_G)^{1/2} = (2 \times 1.6 \times 10^{-19} \times 6 \times 10^{-9})^{1/2}$$

$$\bar{i}_s = 1.4 \times 10^{-14} \text{ AMP}/\sqrt{\text{Hz}}$$

So with 1 meg R_L , Noise due to $i_s =$

$$\bar{e}_n|_{i_s} = 1.4 \times 10^{-14} \times 1 \times 10^6 \text{ volts}/\sqrt{\text{Hz}} = 14 \text{ nV}/\sqrt{\text{Hz}}$$

c) @ inverting input ($10 \text{ k}, R_L$)

$$\bar{e}_n|_{i_s} = 1.4 \times 10^{-14} \times 10^4 = 0.14 \text{ nV}/\sqrt{\text{Hz}}$$

d) Input Resistors @ non-inv. input $\leq 1 \text{ meg}$
@ inverting $\leq 10 \text{ k}$

$$\text{So } \bar{e}_n|_{\text{meg}} = (4KTR)^{1/2} \text{ V}/\sqrt{\text{Hz}} = 1.34 \times 10^{-7} \text{ V}/\sqrt{\text{Hz}}$$

$$= \underline{\underline{134 \text{ nV}/\sqrt{\text{Hz}} @ 50^\circ \text{C}}}$$

$$\bar{e}_n|_{10 \text{ k}} = (4KTR)^{1/2} \text{ V}/\sqrt{\text{Hz}} = 13.4 \text{ nV}/\sqrt{\text{Hz}} @ 50^\circ \text{C}$$

ALPS

Lead Chloride Permeability Circuit

Calc

Finally Total output noise = r.m.s. combination of all sources

$$= \sqrt{(10\text{ nV})^2 + (10\text{ nV})^2 + (14\text{ nV})^2 + (14\text{ nV})^2 + (134\text{ nV})^2 + (13.4\text{ nV})^2}$$

$i_{n_c}, \quad i_{n_{fe}}, \quad i_{n_{fb}}, \quad i_{n_{fd}}, \quad R_{in}, \quad R_{ox}$

$$= \underline{136 \text{ nV} / \sqrt{47}} \quad \text{is almost all due to } R_L (i_{n_{fb}})$$

IN 0.2 Hz BANDWIDTH @ 17 Hz

THE EQ. INPUT NOISE (PREAMP ONLY) IS THEN

$$\frac{136 \text{ nV}}{\sqrt{47}} \times \sqrt{0.2 \text{ Hz}} = \underline{61 \text{ nV rms @ 50 Hz}}$$

$$\text{Noise} \approx \underline{57 \text{ nV rms @ 25 Hz}}$$

TRW SYSTEMS GROUP		PREPARED BY: <u>1.3E</u>	ATTACHMENT	PAGE <u>4A</u> OF
PROJECT <u>1.3E</u>	SUBJECT <u>Coated Detector Gm - 216</u>	DATE <u>5/14/75</u>		

MEASURED NOISE Performance

INPUT TERMINATED IN 1MΩ

<u>f_{Hz}</u>	<u>E_n (NP302 with 647 Noise Fig)</u>
30Hz	200μV
60Hz	"
100Hz	"
200Hz	"
500Hz	"

Expected 1MΩ Resistor Noise:

$$\begin{aligned}
 &= 1.27 \times 10^{-4} \sqrt{R \Delta f} = \\
 &= 1.27 \times 10^{-4} \sqrt{10^6 \times 1000} \times \sqrt{\Delta f} \\
 &= 1.27 \times 10^{-4} \times \sqrt{10^9} \times \sqrt{\Delta f} \\
 &= 121.2 \mu V \times \sqrt{\Delta f} \\
 &= 121.2 \mu V \times \sqrt{6} = \underline{297 \mu V \text{ rms}}
 \end{aligned}$$

Measured noise referred to input

$$= \frac{200 \mu V}{6.50} = \underline{308 \mu V \text{ rms}} \quad \text{OR } 125.7 \mu V / \sqrt{Hz}$$

Noise with input shorted

$$\approx \frac{25 \mu V}{6.50} = 38.5 \mu V \text{ in } 6Hz BW$$

$$\text{So noise density} \approx \frac{38.5}{\sqrt{6}} \mu V / \sqrt{Hz}$$

$$\approx \underline{15.7 \mu V / \sqrt{Hz}}$$

which compares with fed.
diode circuit result.

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7. AMPLIFIER STABILITY (GAIN / PHASE MARGIN)

a) FIRST STAGE RESISTANCE

$$\text{Roll off } f_{\text{req}} = \frac{1}{2\pi \times 2R_D \times C} = \frac{.159}{2 \times 26.1k \times 470pf} = 6.48Kc$$

$$K_i = \frac{S_o}{(24.5 \times 10^{-6})5 + 1}$$

b) \Rightarrow Lowpass op-amp with 100pf Compensation.

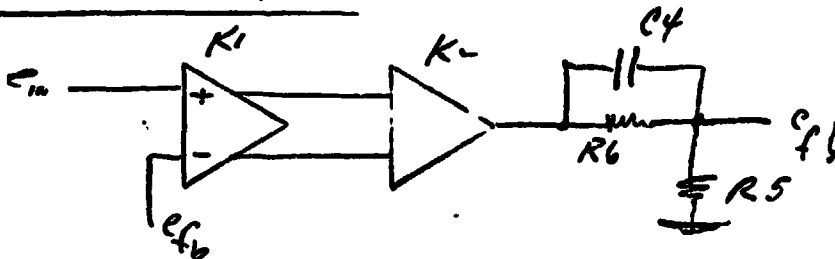
$$A_{DC} = 3 \times 10^5$$

$f_T \equiv 750 \text{ Kc}$ WITH $C_{cap} = 30 \text{ pF}$

$\therefore f_r = 225 \text{ kc}$ $C = 10 \mu\text{f}$
 $\therefore -3 \text{ db } f_{cu} = 75 \text{ Hz}$

5. $\therefore -384 \text{ Hz} = -75 \text{ Hz}$
Transfer function = $\frac{A_2}{\tau_2 s + 1} = \frac{3 \times 10^5}{.212 s + 1}$

Loop gain is then :



TRW SYSTEMS GROUP		PREPARED BY: <i>NYE</i>	ATTACHMENT	PAGE 6 OF
PROJECT <i>MAPS</i>	SUBJECT <i>PbSe Preamp/Filter</i>	DATE <i>5/5/75</i>		

7 cont

RSSWE Program for OPEN Loop Response is Then :

LIST.FAMP2

```

500 FOR F=1,10,20,40,100,200,400,1E3,2E3,4E3,1E4,2E4,4E4
2000 DATA 15,24,3E-6,3E5,.212,494E3
2001 DATA 1E4,6E-12,10E6,.02E-6
2100 DATA 20,30,50,30,2
2101 DATA 2,2,20,20
2200 DATA A1,T1,A2,T2,F3
2201 DATA B3,C3,A1,C1
2300 DATA "PBEN FSEAMP RESPONSE"
3000 X1= A0/CMPLX(1,A1*W)
3010 X2=A2/CMPLX(1,A3*W)
3015 Z1= A4/CMPLX(1,W*A4*A5)
3020 B=A5*(A5+Z1)
3030 Z2=CMPLX(1,W*A7*A8)/CMPLX(1,W*A7*A8)
3040 X1=X1*B*B
3050 X2=Z2*(1/B)*(X1/(X1+1))
3200 Z=X2

```

NOTE: LINE 3700

X = X1 for open Loop Response
X = X2 for Closed Loop Response

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TRW SYSTEMS GROUP		PREPARED BY: <i>NFE</i>	ATTACHMENT	PAGE 7 OF
PROJECT <i>1165</i>	SUBJECT <i>P15e PREAMPLIFIER</i>	DATE <i>5/29/75</i>		

7000
Open Loop Response Data:

FILE NAME: *1165*

FREQ	GAIN(DB)	+TOL.	-TOL.(DB)	PHASE	TOL(DEG)
1.00000E+00	9.44990E+01	2.980	-4.574	-53.101	8.252
1.00000E+01	7.64152E+01	3.339	-5.494	-85.686	1.293
2.00000E+01	7.04129E+01	3.344	-5.507	-87.806	.646
4.00000E+01	6.43969E+01	3.345	-5.511	-88.641	.340
1.00000E+02	5.64399E+01	3.345	-5.512	-89.360	.29e
2.00000E+02	5.04214E+01	3.345	-5.512	-89.366	.536
4.00000E+02	4.44081E+01	3.345	-5.512	-89.057	1.062
1.00000E+03	3.64989E+01	3.346	-5.512	-87.927	2.602
2.00000E+03	3.06367E+01	3.349	-5.522	-86.283	4.364
4.00000E+03	2.50549E+01	3.337	-5.627	-84.620	7.713
1.00000E+04	1.79505E+01	3.608	-6.284	-86.397	7.877
2.00000E+04	1.22629E+01	3.765	-6.793	-90.796	5.061
4.00000E+04	6.28291E+00	3.825	-7.000	-96.788	2.728
1.00000E+05	-2.12199E+00	3.844	-7.064	-110.130	1.218
2.00000E+05	-9.55212E+00	3.845	-7.069	-126.986	.937

THE ARGUMENTS AND TOLERANCES ARE:

A1	A0	15	20	R2	A5	10000	2
T1	A1	.245E-04	30	C3	A6	.62E-10	2
A2	A2	300000	30	P1	A7	10000000	20
T2	A3	.212E+00	30	C1	A8	.2E-07	20
P3	A4	499000	2				

PROGRAM: PBRN PREAMP RESPONSE
05 30 75. 08.36.10.

*So we see phase MARGIN Exceed: 70°
& ADEQUATE STABILITY IS INSURED.*

TRW SYSTEMS GROUP		PREPARED BY: <i>WJ</i>	ATTACHMENT	PAGE 1 OF
PROJECT <i>WJPS</i>	SUBJECT <i>PLC PREAMPLIFIER</i>	DATE <i>5/20/75</i>		

8 Closed Loop Response DATA

FREQ	GAIN(MAG)	TOL (%)	PHASE	TOL (DEG)
1.00000E+00	3.98377E+01	11.311	38.5001	7.895
1.00000E+01	5.07324E+01	2.778	4.4320	1.281
2.00000E+01	5.05388E+01	2.773	2.0429	.644
4.00000E+01	5.08878E+01	2.773	.6684	.383
1.00000E+02	5.08879E+01	2.772	-.7221	.139
2.00000E+02	5.05593E+01	2.770	-2.1273	.122
4.00000E+02	5.07408E+01	2.763	-4.5894	.209
1.00000E+03	4.99325E+01	2.718	-11.5924	.509
2.00000E+03	4.73317E+01	2.603	-22.4612	.965
4.00000E+03	3.59165E+01	2.513	-40.1432	1.701
1.00000E+04	2.29373E+01	2.393	-67.7312	3.735
2.00000E+04	1.23746E+01	3.641	-84.9447	7.359
4.00000E+04	6.20434E+00	8.188	-101.0533	13.867

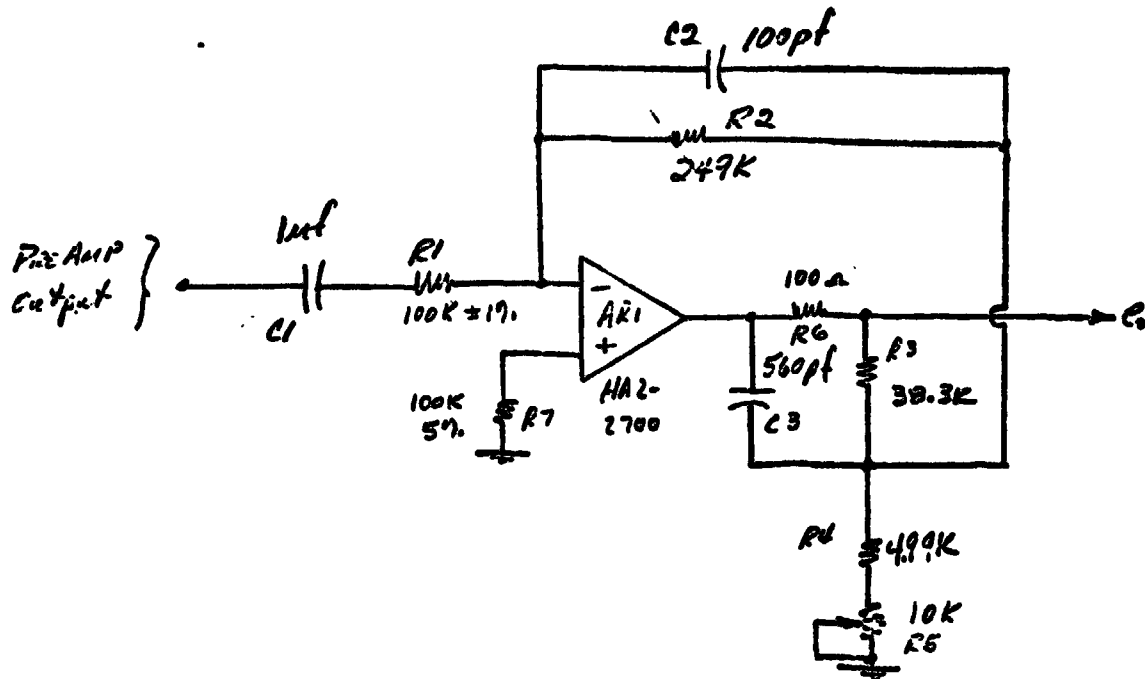
THE ARGUMENTS AND TOLERANCES ARE:

R1	R0	15	20	R2	R5	10000	2
T1	R1	.243E-04	30	C3	R6	.62E-10	2
R2	R2	300000	30	P1	R7	10000000	20
T2	R3	.212E+00	30	C1	R8	.2E-07	20
R3	R4	495000	2				

PROGRAM: PCBN FREAME RESPONSE
05.20.75. 08.12.06.

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TRIV SYSTEMS GROUP		PREPARED BY: <u>ME</u>	ATTACHMENT	PAGE 1
PROJECT <u>MAPS</u>	SUBJECT <u>Lab. 1 - End Amplifier</u>	DATE		OF



1] INPUT Coupling Network

$$f_{\text{Low}} = \frac{.159}{\text{inf} \times 100K} = 1.59 \text{ Hz}$$

(MIN. Chopping freq = 170 Hz)

2] MID-BAND GAIN

$$= \left(\frac{R_2}{R_1} \right) \left(\frac{R_3 + R_4 + R_5}{R_4 + R_5} \right) = 2.49 \left(\frac{48.3}{9.99} \right) = 12.04 \text{ NOMINAL}$$

$$= 2.49 (3.56) = 8.85 \text{ MINIMUM}$$

$$= 2.49 (8.68) = 21.6 \text{ MAX.}$$

3] HIGH FREQUENCY Roll-off — Set by $R_2 C_2$ and $R_3 C_3$ time constants.

$$f = \frac{.1}{249 \times 10^3 \times 100 \times 10^{-12}} = \frac{1.59 \times 10^{-5}}{2.49 \times 10^{-5}} = 6.4 \text{ Kc}$$

APPENDIX D

DESIGN ANALYSIS REPORT, CHOPPER MOTOR DRIVE AND PICKOFF CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides design and analysis documentation for the chopper motor drive and pickoff circuits of the MAPS Breadboard.

2.0 CIRCUIT REQUIREMENTS

The function of these circuits is to provide a variable voltage, variable frequency 2-phase square wave voltage drive to a synchronous motor and to provide the S and R demodulation timing signals.

a) Internal Oscillator

Provide an internal clock oscillator which will provide three different switch selectable motor operating speeds. The basic oscillator operating frequencies shall be 125HZ, 458HZ, and 916HZ.

Provision shall also be made to accept an external clock input.

b) Two-Phase Drive Logic

Provide two square wave logic signals with a 90 degree phase relationship which have an output frequency which is one-fourth that of the clock oscillator.

c) Motor Drivers

Two separate ϕA and ϕB motor drive circuits shall be provided which have the following characteristics:

- Low impedance square wave output
- Output voltage - within ± 1 volt of the supply voltage for a range of supply voltages from ± 16 volts to ± 60 volts.
- Drive capability - must drive synchronous motor with characteristics per specification 2B006.

d) Pickoff Circuits

The chopper disc pickoff circuits shall provide wheel timing signals as follows:

- Lamp bias networks - Each of 2 light emitting diodes shall be provided with a bias current adequate to give sufficient detector signals.
- Pickoff Amplifier - The outputs of 2 separate phototransistors shall be sensed and a 0 to + 5 volt square wave developed by the use of a zero crossing detector.
- Timing Adjustment delay circuit - a delay circuit shall be provided for each pickoff signal which allows an adjustable delay of the square wave signal by up to 1 percent of its period.

3.0 CIRCUIT DESCRIPTION AND ANALYSIS RESULTS

The motor drive circuitry is shown on sketch schematic SK-MAPS-BB-101 and the pickoff circuitry is shown on sketch schematic SK-MAPS-BB-103.

The attached circuit analyses sheets provide an assessment of circuit performance.

3.1 Motor Drive Circuits

The basic motor drive clock signal is obtained from an SE55L timing IC which is connected as a free running square wave oscillator.

The two 90° phase related drive signals are then obtained from a cross connected 2 bit shift register. (See analysis page 2.)

The drive signals are increased to 15 volts peak-to-peak by a 2N2222 stage and then ac coupled to the output drivers. AC coupling is used so that the loss of the clock signal or external sync will result in the removal of all motor voltages.

The output stage consists of a complementary pair of transistor switches which alternately switch one side of the motor winding between the plus and minus supply voltage. Clamp diodes (IN4944's) across the switches provide current paths for transient inductive motor currents.

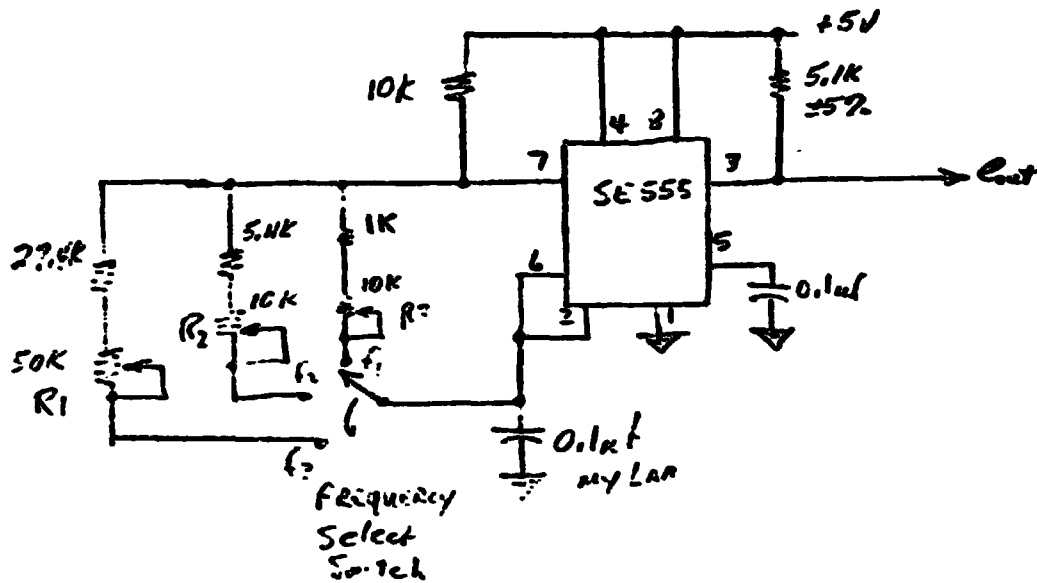
3.2 Scene and Reference Pickoff Circuits

Two phototransistor and light emitting diode pairs provide the pickup of the S and R timing signals. As is shown on analysis page 5, a HA2-2700 IC operational amplifier is connected as a voltage comparator with positive feedback to develop a square wave output from the phototransistor signal. The phototransistor output is AC coupled so the circuit switches only on zero crossings and is immune to steady state light level responses of the phototransistor.

Analysis pages 6 and 7 show the timing of the adjustable delay circuit which provides an overall timing signal delay. The delay equals the period of the one shot circuit using the 2N2222 transistor.

i) INTERNAL CLOCK OSCILLATOR

A) Circuit



OSCILLATOR = SE555 CONNECTED AS INSTABLE
MULTIVIBRATOR.

$$f_{osc} = \frac{1.44}{(R_1 + 2R_2)C}$$

where R_2 = resistance from pin 7 to +5V
 R_3 = resistance from pin 7 to ground
 C = Capacitance, pin 6 to ground

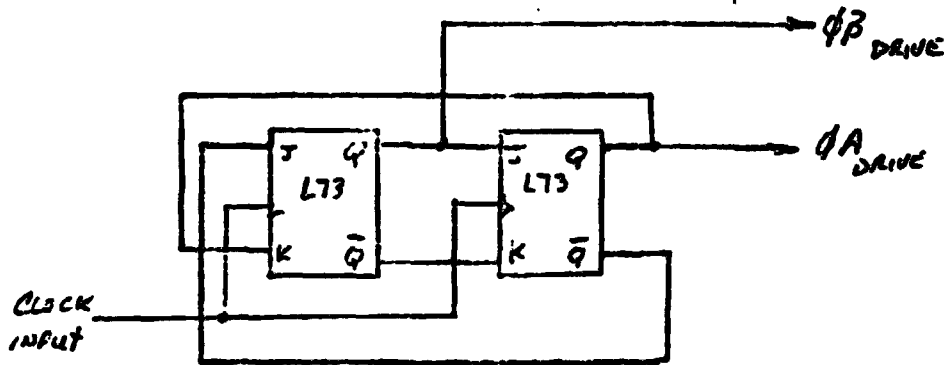
POTS R_1, R_2 & R_3 set 3 separate frequencies
 of 125Hz, 458Hz, and 916Hz.

PROJECT <i>1000</i>	SUBJECT <i>SYSTEMS DESIGN CIRCUITS</i>
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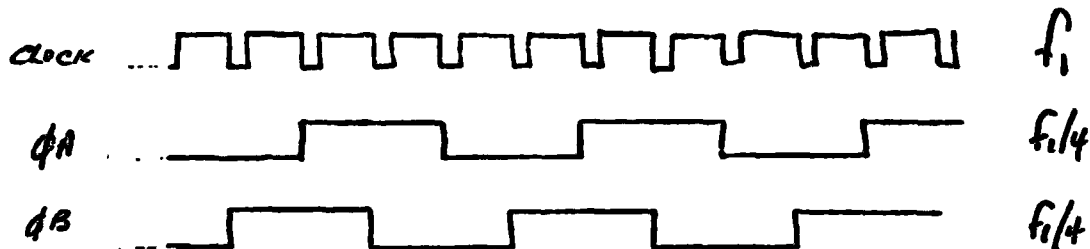
2) 10° PHASE SHIFT NETWORK

2 BIT SHIFT REG. PROVIDES ϕA & ϕB CLOCK WAVEFORMS

a) CIRCUIT



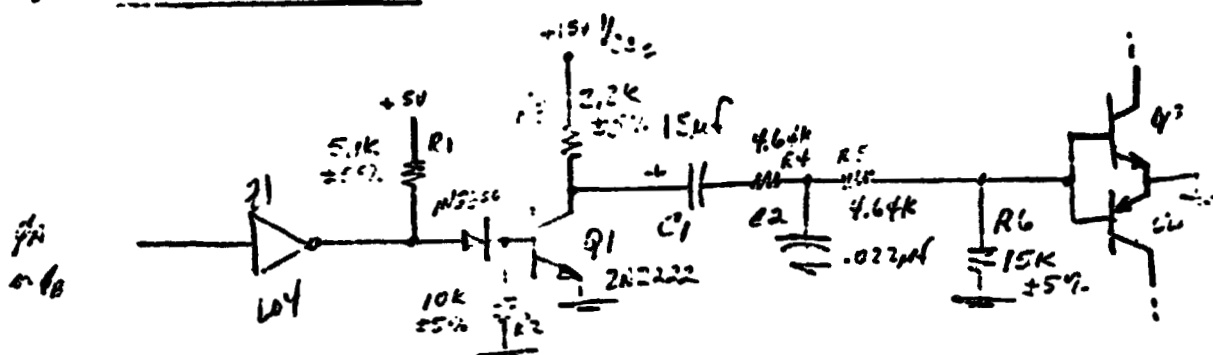
b) TYPICAL WAVEFORMS



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TRW SYSTEMS GROUP			PREPARED BY:	ATTACHMENT	PAGE 3 OF
PROJECT	SUBJECT	DATE			

3) DRIVER STAGE



Voltage to output stage = $\pm V_{CE}(Q3 \& Q4)$

(a) OUTPUT DRIVE
BASE CURRENT

$$= \frac{V_2 (V_{CC2} - V_{BE})}{R_3 + R_4 + R_5} - \frac{V_{BE}}{R_6} = \frac{\frac{1}{2} (15 - .75)}{(2.2k + 2 \cdot 4.6k)} - \frac{.75}{15k}$$

$$= 0.57 \text{ mA Nominal}$$

(b) MINIMUM OUTPUT BASE DRIVE

$$= \frac{1}{2} \left(\frac{14.75 - .85}{2.2k + 2(4.6k)(1.03)} \right) - \frac{.85}{15k(1.8)} = 0.53 \text{ mA}$$

(c) MAX Collector Current Q1

$$= \frac{15.25V}{2.2k(1.8)} = 9.66 \text{ mA}$$

(d) MINIMUM BASE DRIVE, Q1 = $\frac{4.75 - V_{CE} - V_2}{R_1} - \frac{V_{BE}}{R_2}$

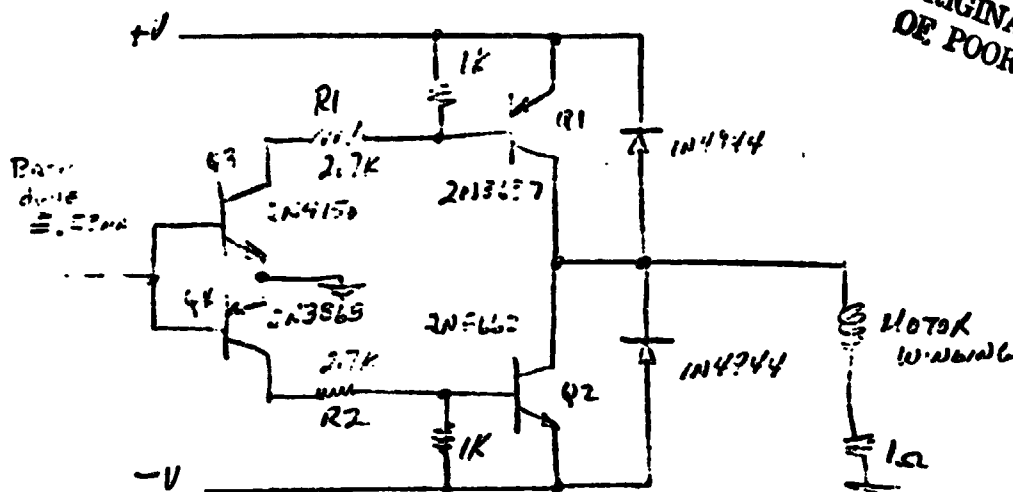
$$= \frac{4.75 - .85 - .75}{5.1k(1.2)} - \frac{.85}{10k(1.5)} = 0.41 \text{ mA}$$

$$\beta \geq \frac{9.66}{.41} \geq 21.2 \text{ is Required}$$

(e) MAX CURRENT SINK BY Q1 IS $\frac{5.25}{5.1k(1.8)} = 1.3 \text{ mA}$

LOW CAIN SINK 2.0mA & DRIVE IS OK.

4) OUTPUT STAGE



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(a) CASE I, $V_{cc} = \pm 28V$, Low freq.

Load Current

@ Low freq $\pm 28V$ is determined by Motor R
of 265Ω

$$I_{Peak} = \frac{28V}{265\Omega} = 106mA$$

$$I_B(Q1 \sim Q2) = \frac{V_{cc} - V_{BE} - V_{D1}(Q3 \sim Q4)}{R1 \sim R2} - \frac{V_{BE}}{1K}$$

$$\geq \frac{28 - .8 - .3}{2.7K(.8)} - \frac{.8}{1K(.8)} \geq 7.3mA$$

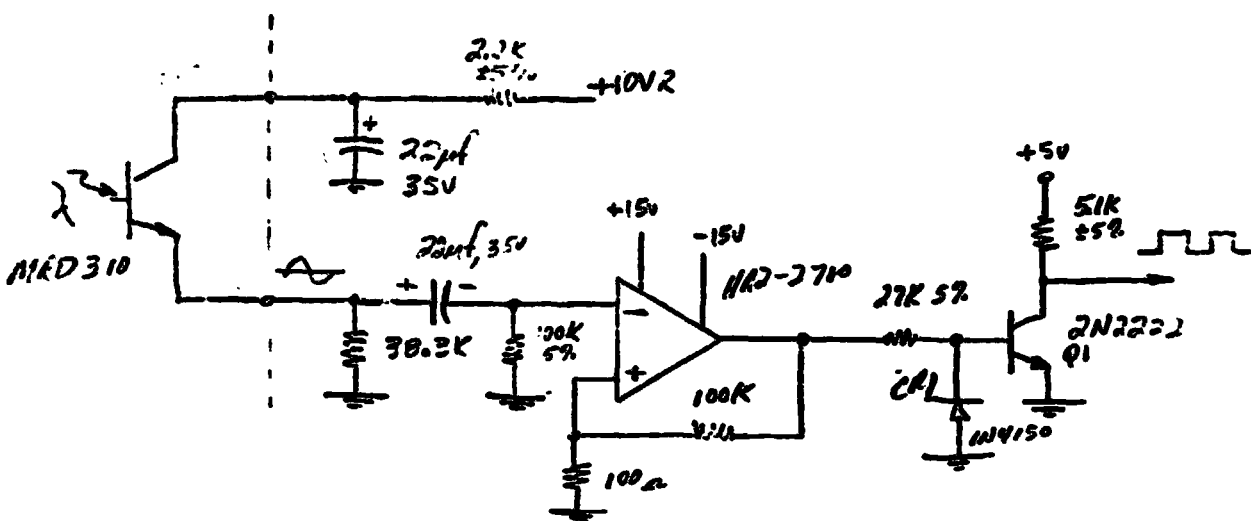
$$\therefore \beta(Q1 \sim Q2) \geq \frac{106}{7.3} \geq 14.5 \text{ is needed}$$

(b) Q3 & Q4 DRIVE

$$I_{C \max}(Q3 \sim Q4) = \frac{28V - .65 - .1}{2.7K(.8)} = 12.62mA$$

$$\therefore \beta(Q3 \sim Q4) \geq \frac{12.62}{.53} \geq 23.8 \text{ is required.}$$

S + R Pickoff Amplifiers



1) HA2-2700 ACTS AS ZERO CROSSING SQUARE AMPLIFIER TO AC SIGNALS.

2) Positive feedback

$$= \pm 14V \times \frac{100}{10^5} = \pm 14 \text{ MILLIVOLTS}$$

3) BASE DRIVE TO Q1

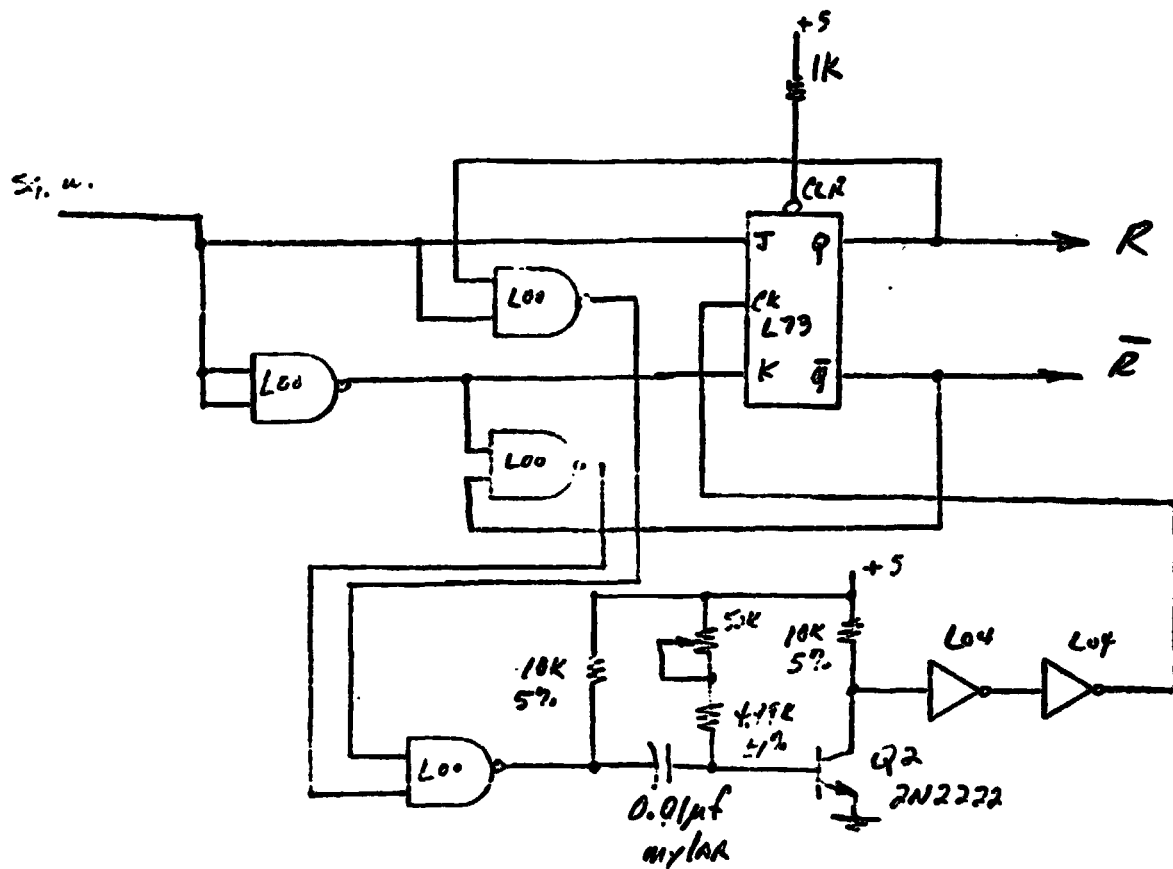
$$\geq \frac{12V}{27K} \geq .44mA$$

Q1 Collector Current $\approx 1.5mA$ including Load loads

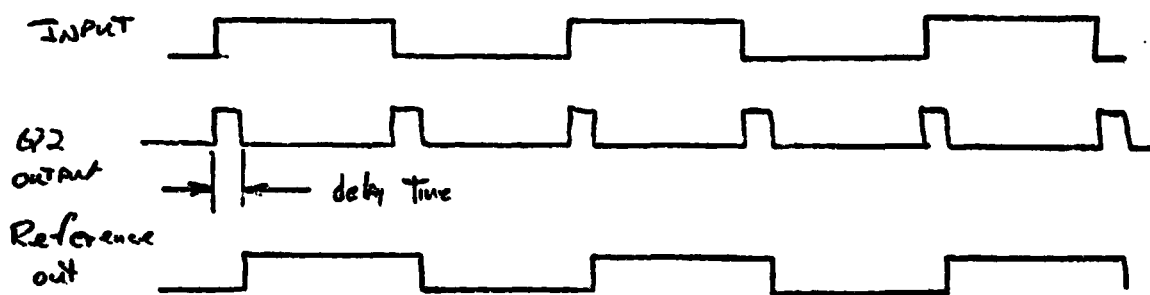
\therefore Q1 operates at forced β of < 10 .

4) DIODE CR1 PROVIDES Reverse Bias when Q1 is off.

S & R Reference Delay Circuits



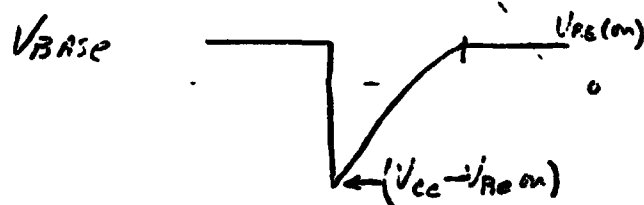
1) Circuit Timing



Delay is set by one-shot ckt.

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ONE SHOT TIME DELAY



$$So \ V_B = -(V_{cc} - V_{BE}) + [V_{cc} - V_{low} + (V_{cc} - V_{BE})] e^{-t/RC}$$

where V_{low} is

V_{low} = Low State Voltage of LOG GAT.

$$\therefore t_p = RC \ln \left[\frac{2V_{cc} - V_{SAT} - V_{BE}}{V_{cc}} \right]$$

WITH POT AT MID RANGE of 25K

$$Nominal \ t_p = 30 \times 10^3 \times 10^{-6} \ln \left[\frac{10 - 0.05 - 0.75}{5} \right]$$

$$= 0.183 \text{ milliseconds}$$

Period of S Reference = 20MS

So Delay $\approx 0.9\%$ Nominal

Stability of t_p

$$\bar{t}_p = 30K(1.05)(0.1 \times 10^{-6})(1.03) \ln \left[\frac{10(1.05) - 0.02 - 0.6}{5(1.05)} \right]$$

$$= 0.205 \text{ millisecc MAX}$$

$$\underline{t}_p = 30K(0.95)(0.1 \times 10^{-6})(0.97) \ln \left[\frac{10(0.95) - 0.2 - 0.85}{5(0.95)} \right]$$

$$= 0.159 \text{ MS MIN}$$

If $\pm 13\%$ w.c. of Period, Then 13% of total delay is only $\pm 0.13\%$ of Timing interval D-10

APPENDIX E

DESIGN ANALYSIS REPORT TEMPERATURE SENSING AND CONTROL CIRCUITS OF THE MAPS BREADBOARD

1.0 SCOPE

This report provides the design analysis documentation for the three blackbody temperature sensing circuits, for the three detector temperature sensing and control circuits and for the on-off temperature controller circuit.

2.0 CIRCUIT REQUIREMENTS

2.1 Room Temperature Blackbodies

For each of 2 unheated blackbodies, provide an analog voltage proportional to temperature over a minimum range of 7°C to 37°C. The output signal range shall be ± 5 volts with a measurement accuracy of $\pm 0.25^\circ\text{C}$.

2.2 Heated Blackbody

For the heated blackbody, provide the analog output over a minimum temperature range of 67°C to 87°C with an accuracy of $\pm 0.25^\circ\text{C}$. The output signal range shall be $\pm 5\text{V}$ nominal.

2.3 Cooled Detectors

For each of 3 cooled detectors, an analog voltage output shall be generated using the thermistor internal to the detector (per PIN 8D007). The measurement range shall be a minimum of -65°C to -90°C with a measurement accuracy of $\pm 3^\circ\text{C}$ with individual thermistor calibration.

In addition, the temperature readout voltage shall be compared with a set point voltage and the difference signal used to control the voltage applied to each detector thermoelectric cooler to maintain a constant detector temperature.

2.4 On/Off Blackbody Heater Driver

An on/off temperature controller shall be provided which switches 28V, 10 watts max, to the blackbody heater.

The set point temperature shall be adjustable from 72 to 80°C.

The switching point dead zone shall be as required for $\pm 3^{\circ}\text{C}$ temperature control.

3.0 CIRCUIT DESCRIPTIONS

3.1 Temperature Sensing Circuits

The six temperature sensing circuits are shown on sketch schematic SK-MAPS-BB-104. The circuits are identical in the sense that a thermistor-resistor bridge circuit and a gain scaling isolation amplifier are used in all cases.

The three blackbody sensing circuits use YSI precision thermistors which provide matched interchangeable temperature/resistance characteristics to within ± 0.5 percent.

The three cooled detector circuits use the thermistors internal to the detector. Because of the wide variation in thermistor characteristics from detector to detector, a selectable shunt resistance is placed across the thermistor in each case. Individual circuit calibration is still necessary however.

3.2 Blackbody Heater Drive

The blackbody heater drive circuitry and the 3 detector T.E. cooler control circuits are shown on sketch schematic SK-MAPS-BB-101.

Transistors Q12 (2N2222) and Q13 (2N5153) comprise the heater on/off voltage switch. A Harris 2700 operational amplifier is used as a voltage comparator to drive the voltage switch. The blackbody temperature voltage is then compared with a set point voltage at the input of the voltage comparator to provide the control action. Positive feedback around the comparator sets up the switching dead zone.

3.3 Thermoelectric Cooler Controllers

The T.E. cooler drive and control circuits are shown on sketch schematic SK-MAPS-BB-101. Each T.E. cooler is provided with a low impedance drive voltage from a darlington connected emitter follower circuit. The emitter follower is driven by a gain of 100 control amplifier which uses an LM108A I.C. operational amplifier.

The control amplifier compares a temperature set point voltage from a potentiometer voltage divider with the output of the detector temperature sensing circuit and amplifies the difference voltage to provide temperature control.

4.0 CIRCUIT ANALYSIS

The attached sketch sheets provide supporting circuit performance analyses.

Pages 1 through 4 of the attached analysis show a rss uncertainty in the unheated blackbody temperature measurements of ± 37.2 millivolts or $\pm 0.14^{\circ}\text{C}$ at a nominal temperature of 22°C .

Pages 5 through 7 give the program results for the heated blackbody. The rss uncertainty in readout at 77°C is $\pm 0.2^{\circ}\text{C}$.

Pages 8 and 9 cover the cooled detector temperature sensing circuits using data from opto-electronics detector S/N 005. As the data shows a thermistor shunt resistor must be selected for each detector and a separate output calibration curve will be needed because of the differences in the detector thermistors.

Page 10 shows the thermoelectric cooler drive circuitry and feedback control amplifier.

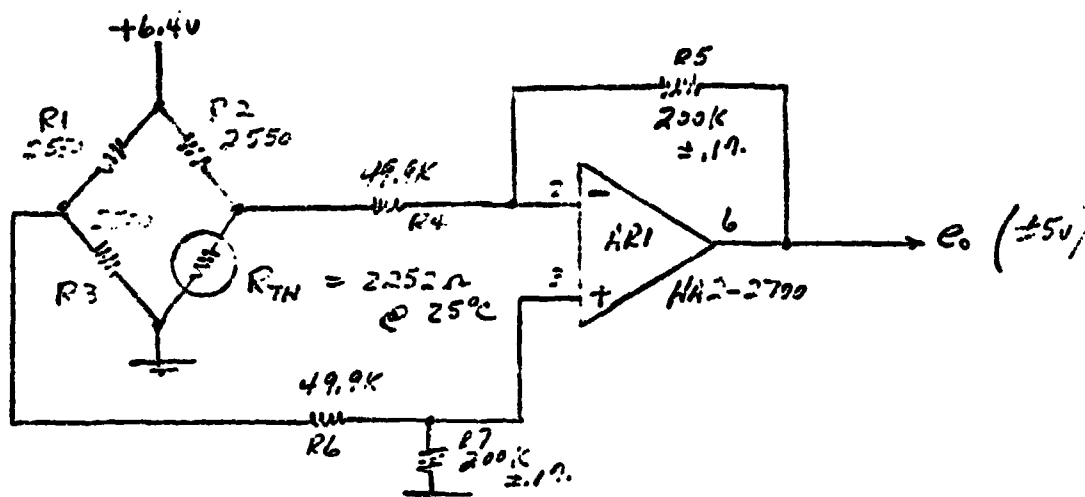
Analysis pages 11 through 14 cover the temperature controller circuit.

An adequate drive capability is shown along with an adequate set point adjustment range and dead zone.

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PROJECT	SUBJECT TEMP SENSE / Control Circuitry	DATE		OF

Room Temp BB Temp Sense Amplifier

1. Circuit



Thermistor Characteristics per YSI #44033

RSSWC1 Program Input

LIST TEMP1

```

500 FOR I=1 TO 16
2001 DATA 7195,5719,5182,4488,3525,3226,2814
2001 DATA 2572,2252,2064,1915,1657,1471,1355,1200,988.8
2001 DATA 1.4,2550,2550,2550,49.9,2550,49.9,2550
2001 DATA 50E-3,50E-3
2100 DATA .5,.5,.5,.5,.5,.5,.5
2101 DATA .5,.5,.5,.5,.5,.5,.5,.5
2110 DATA .25,.05,.05,.05,.05,.05,.05,.05
2111 DATA 0.10
2200 DATA P0,P5,P7,P10,P15,P17,P20
2201 DATA P22,P25,P27,P30,P32,P35,P37,P40,P45
2211 DATA P47,P50,P52,P54,P55,P57
2212 DATA 0.1000
2201 DATA "TEMP SENSE AMPLIFIER"
2300 DATA 10,50,70,100,150,170,200,220,250,270,300,320,350,370,400,450
2301 DATA 40,70,100,150,170
2302 DATA 10,50,70,100,150
2303 DATA 10,50,70,100,150
2304 DATA 10,50,70,100,150
2305 DATA 10,50,70,100,150
2306 DATA 10,50,70,100,150
2307 DATA 10,50,70,100,150
2308 DATA 10,50,70,100,150
2309 DATA 10,50,70,100,150
2310 DATA 10,50,70,100,150
2311 DATA 10,50,70,100,150
2312 DATA 10,50,70,100,150
2313 DATA 10,50,70,100,150
2314 DATA 10,50,70,100,150
2315 DATA 10,50,70,100,150
2316 DATA 10,50,70,100,150
2317 DATA 10,50,70,100,150
2318 DATA 10,50,70,100,150
2319 DATA 10,50,70,100,150
2320 DATA 10,50,70,100,150
2321 DATA 10,50,70,100,150
2322 DATA 10,50,70,100,150
2323 DATA 10,50,70,100,150
2324 DATA 10,50,70,100,150
2325 DATA 10,50,70,100,150
2326 DATA 10,50,70,100,150
2327 DATA 10,50,70,100,150
2328 DATA 10,50,70,100,150
2329 DATA 10,50,70,100,150
2330 DATA 10,50,70,100,150
2331 DATA 10,50,70,100,150
2332 DATA 10,50,70,100,150
2333 DATA 10,50,70,100,150
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2495 DATA 10,50,70,100,150
2496 DATA 10,50,70,100,150
2497 DATA 10,50,70,100,150
2498 DATA 10,50,70,100,150
2499 DATA 10,50,70,100,150
2500 DATA 10,50,70,100,150

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PROJECT MARS	SUBJECT Temp Sensor & Control Circuits	DATE		

PROGRAM OUTPUT for $22^{\circ}\text{C} \pm 15^{\circ}\text{C}$

PCI ANALYSIS

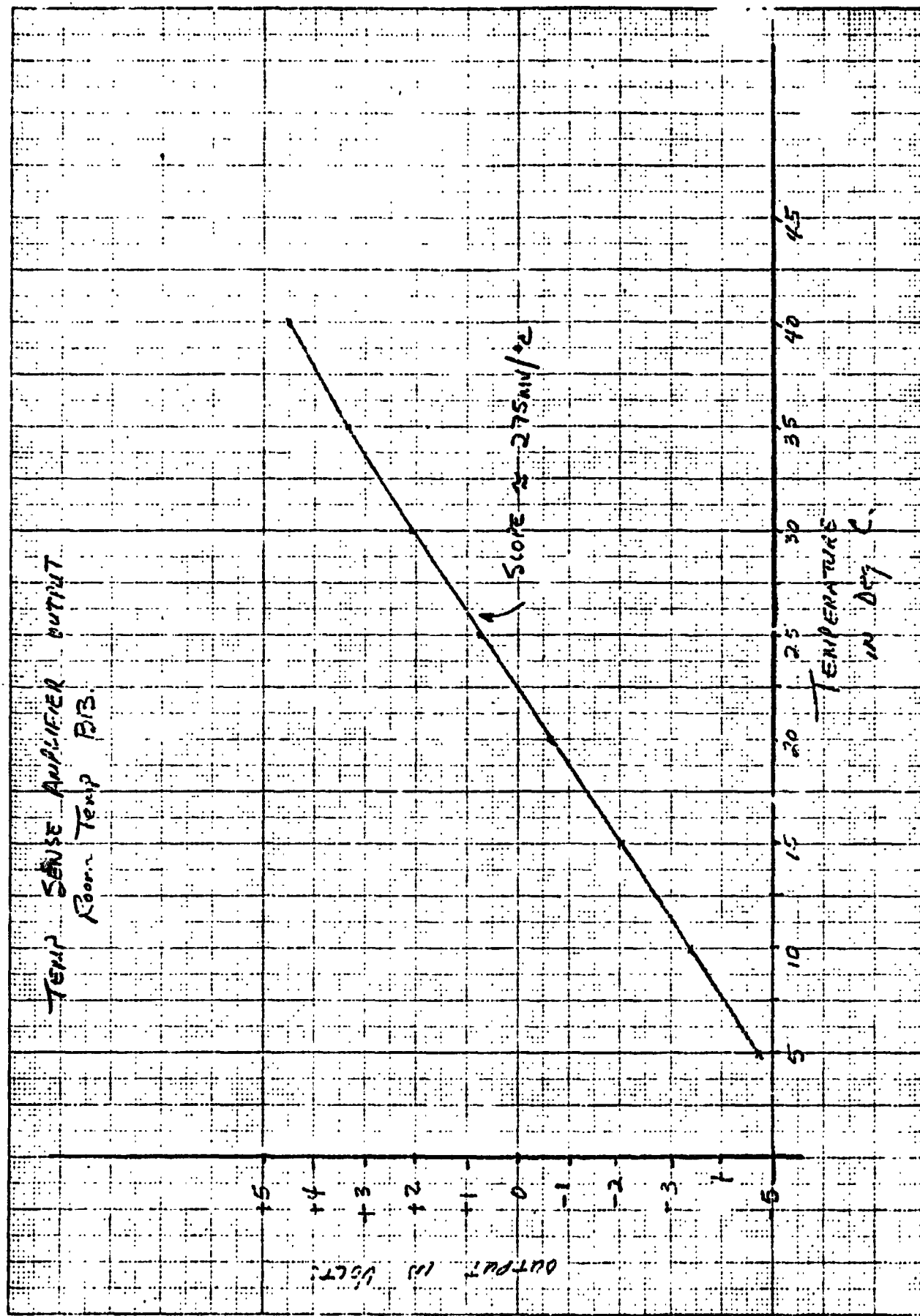
TEMP	VARIABLE	OUTPUT	TOL.	-LIM.	+LIM.
0C		-5.96394E+00	.50	-5.99955E+00	-5.92934E+00
50		-4.72309E+00	.75	-4.75871E+00	-4.68808E+00
70		-4.20094E+00	.05	-4.20656E+00	-4.16531E+00
100		-3.69530E+00	1.00	-3.40137E+00	-3.35922E+00
150		-2.01284E+00	1.02	-2.04956E+00	-1.97611E+00
170		-1.45209E+00	2.54	-1.46892E+00	-1.41506E+00
200		-6.11609E-01	6.07	-6.49770E-01	-5.74507E-01
220		-5.34373E-02	69.64	-9.06499E-02	-1.62258E-02
250		7.73354E-01	4.02	7.36112E-01	3.10595E-01
270		1.31405E+00	2.83	1.27635E+00	1.35125E+00
300		2.10398E+00	1.76	2.06391E+00	2.14104E+00
320		2.61903E+00	1.41	2.58210E+00	2.65596E+00
350		3.36104E+00	1.09	3.32466E+00	3.39802E+00
370		3.82693E+00	.95	3.80043E+00	3.87341E+00
400		4.51968E+00	.80	4.48371E+00	4.55606E+00
450		5.57621E+00	.64	5.54055E+00	5.61188E+00

THE ARGUMENTS AND TOLERANCES ARE:

R0	R0	7255	.5E+00	R37	B3	1355	.5E+00
R5	R1	5719	.5E+00	R40	B4	1200	.5E+00
R7	R2	5100	.5E+00	R45	D5	983.2	.5E+00
R10	R3	4482	.5E+00	VB	B6	6.4	.25E+00
R15	R4	3539	.5E+00	P1	D7	2550	.5E-01
R17	R5	3226	.5E+00	R2	B8	2550	.5E-01
R20	R6	2814	.5E+00	P3	B9	2550	.5E-01
R22	R7	2570	.5E+00	F4	C0	49900	.5E-01
R25	R8	2252	.5E+00	R5	C1	200000	.5E-01
P07	R9	2064	.5E+00	R6	C2	49900	.5E-01
P30	B0	1815	.5E+00	R7	C3	200000	.5E-01
P32	B1	1607	.5E+00	E1	C4	.5E-01	0
R35	B2	1471	.5E+00	E2	C5	.5E-01	10

PROGRAM: TEMP SENSLE AMPLIFIER
05-07-75. 08.28.13.

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TRW
SYSTEMS GROUP

PROJECT
NAPS

SUBJECT
TEMP SENSE & Control Circuits

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DATE		

PER PLOTTED DATA

SLPPE OF output $\approx 275 \text{ mV}/^\circ\text{C}$

UNCERTAINTY IN VOLTAGE OUTPUT @ $22^\circ\text{C} = \pm 37.2 \text{ mV}$

which is $\pm 0.14^\circ\text{C}$

TRIV

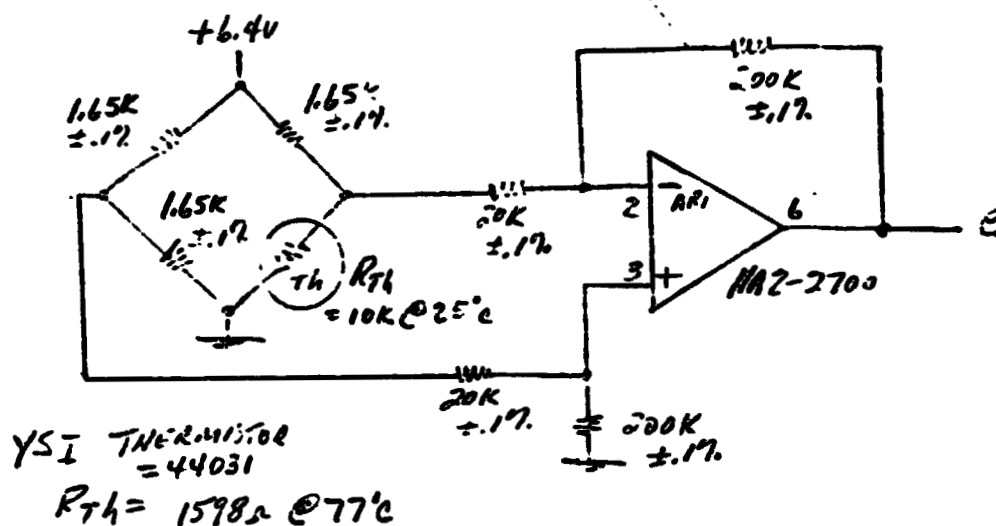
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PAGE 5 OF 6

PROJECT: *ATAP* SUBJECT: *Good Serv & Control Pots*

DATE

HOT SE TEMP SENSE AMPLIFIER



RSSWEL PROGRAM INPUT

L1CT+TEMP2

```

500 FOR T=1 TO 16
2000 DATA 2669.2447.2339.2191.2055.1928.1810
2001 DATA 1700.1592.1503.1414.1332.1255.1163.1116.1053
2010 DATA 6.4.1650.1650.1650.2E4.2E5.2E4.2E5
2020 DATA 50E-3.50E-3
2100 DATA .5.5.5.5.5.5.5.5
2101 DATA .5.5.5.5.5.5.5.5
2110 DATA .25.05.05.05.05.05.05.05
2120 DATA 0.10
2200 DATA F61.F63.F65.F67.F69.F71.F73
2201 DATA F75.F77.F79.F81.F83.F85.F87.F89.F91
2210 DATA V8.F1.F2.F3.F4.F5.F6.F7
2215 DATA E1.E2
2300 DATA "HOT SE TEMP SENSE AMPLIFIER"
2400 DATA 610.630.650.670.690.710.730.750
2401 DATA 770.790.810.830.850.870.890.910
3000 Z1=80*H1.T.1E8*H1.T.
3010 Z2=E7.E8.17.E9.
3020 V1=F6.H1.T.1E8*H1.T.
3030 V2=F6.F4.F7.E9.
1100 Z= V2*(C3.C3+C2+Z2)/(1+C1*V1+C1*V1+Z1)+C1*V1+Z1+
+ C4-C5.

```

SYSTEMS 100 REV. 2-68

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PROJECT
AIRS

SUBJECT

TEMP. SENSE & CONTROL CTS

PREPARED BY:

RAC

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DATE

PAGE

6
OF

Program output for 77°C ± 10°C

TEMPERATURE
H-M.I.C.VOLTAGE
OUTPUT

TOL.

-LIN.

+LIN.

610	-7.15672E+00	1.24	-7.24536E+00	-7.06626E+00
630	-6.27064E+00	1.44	-6.29232E+00	-6.11417E+00
650	-5.25246E+00	1.71	-5.34202E+00	-5.16290E+00
670	-4.33650E+00	2.10	-4.37852E+00	-4.19649E+00
690	-3.35242E+00	2.71	-3.42863E+00	-3.24201E+00
710	-2.37153E+00	3.63	-2.46235E+00	-2.28083E+00
730	-1.41325E+00	4.44	-1.50430E+00	-1.32220E+00
750	-4.56707E-01	19.99	-5.47993E-01	-3.65421E-01
770	4.40492E-01	18.63	3.99032E-01	5.81952E-01
790	1.43010E+00	6.40	1.33352E+00	1.52167E+00
810	2.36546E+00	3.87	2.27385E+00	2.45712E+00
830	3.27802E+00	2.79	3.18726E+00	3.37053E+00
850	4.10566E+00	2.19	4.09403E+00	4.27727E+00
870	5.06907E+00	1.20	4.98876E+00	5.17175E+00
890	5.85652E+00	1.53	5.26517E+00	6.04788E+00
910	6.82204E+00	1.34	6.73052E+00	6.91322E+00

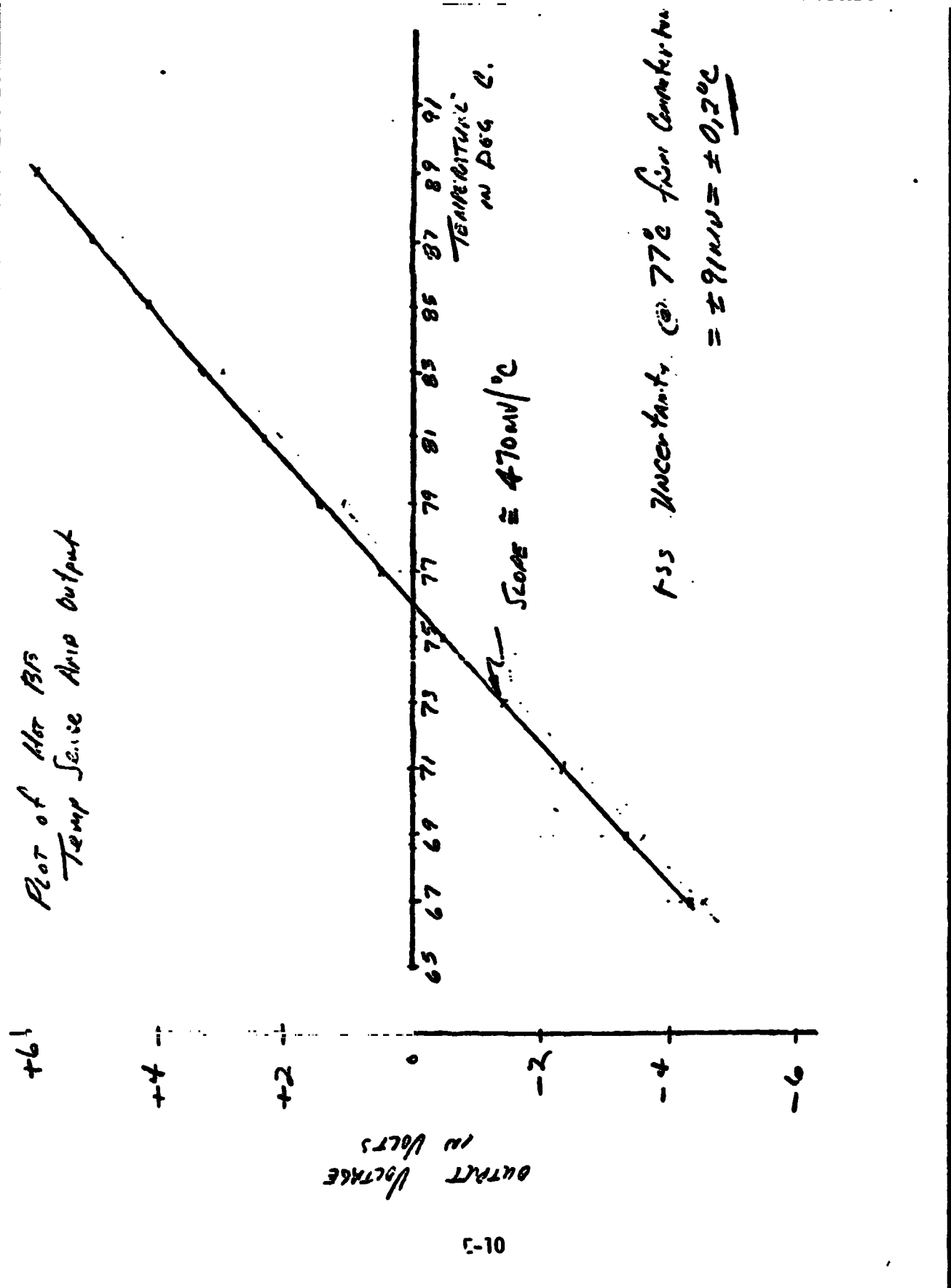
THE ARGUMENTS AND TELEPHONES ARE.

P61	A0	2669	.5E+00	F67	B3	1183	.5E+00
P63	A1	2497	.5E+00	R89	B4	1116	.5E+00
P65	A2	2339	.5E+00	F91	B5	1053	.5E+00
P67	A3	2191	.5E+00	VB	B6	6.4	.25E+00
P69	A4	2055	.5E+00	P1	B7	1650	.5E-01
P71	A5	1922	.5E+00	P2	B8	1650	.5E-01
P73	A6	1810	.5E+00	P3	B9	1650	.5E-01
P75	A7	1700	.5E+00	P4	C0	20000	.5E-01
P77	A8	1598	.5E+00	P5	C1	20000	.5E-01
P79	A9	1505	.5E+00	P6	C2	20000	.5E-01
P81	B0	1414	.5E+00	P7	C3	20000	.5E-01
P83	B1	1332	.5E+00	E1	C4	.5E-01	0
P85	B2	1255	.5E+00	E2	C5	.5E-01	10

PROGRAMS: HUF IS TEMP SENSE AMPLIFIER
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PROJECT 1400S		SUBJECT Temp Sense Contn Circuits		TRW SYSTEMS GROUP		PREPARED BY: NFE	ATTACHMENT	PAGE 7 OF
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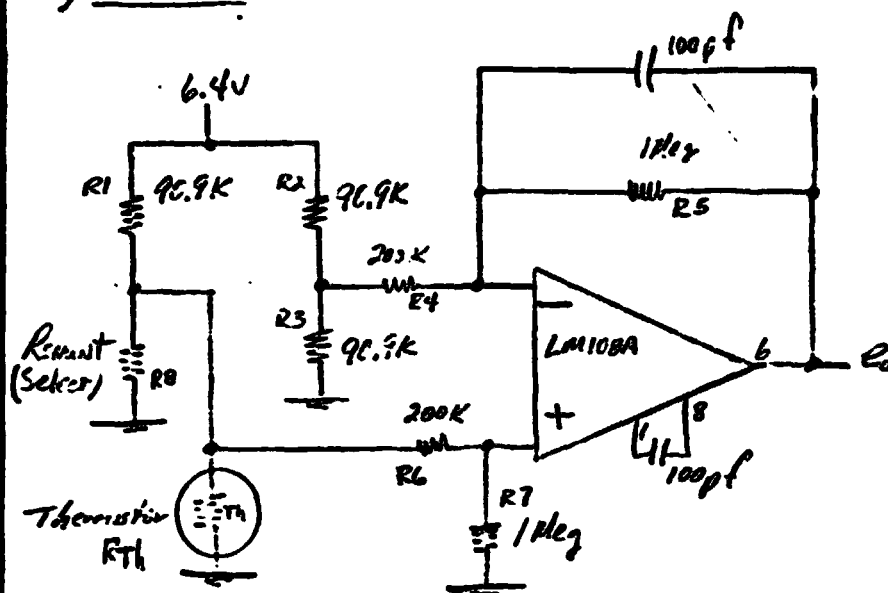
Cooled detector Temperature Readout

DATE

10/9/75

OF

1) Circuit



2) Thermistor Shunt

BECAUSE OF A WIDE RANGE OF VARIATION IN THERMISTOR RESISTANCE VS Temperature, A SELECTABLE PARALLEL SHUNT RESISTANCE IS USED TO NULL THE BRIDGE AT $\approx -75^{\circ}\text{C}$.

3) THERMISTOR CHARACTERISTICS

3 TYPICAL THERMISTORS FROM OPTO-ELECTRONICS DATA ARE SHOWN BELOW

Temperature	Resistance S/N 005	Resistance S/N 004	Resistance S/N 006
-40C	31.3K	34K	
-45C	38K	40.5K	
-50C	47K	54K	37K
-55C	59K	71K	48K
-60C	75K	100K	62K
-65C	97K	145K	84K
-70C	129K	385K	110K
-80C	250K	710K	210K
-85C	378K		300K

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Cooled detector Readout

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OF

4) OUTPUT CHARACTERISTICS

FOR Ckt Shown:

$$E_o = \left(\frac{-R_5}{R_4 + R_2 \parallel R_3} \right) \left(\frac{6.4 R_7}{R_1 + R_3} \right) + \left(1 + \frac{R_5}{R_4 + R_2 \parallel R_3} \right) \left(\frac{6.4 R_4}{R_1 + R_2} \right) \left(\frac{R_7}{R_6 + R_7 + R_1 \parallel R_4} \right)$$

where
 $R_2 = R_{Th} \parallel R_8 = \frac{R_{Th} R_8}{R_{Th} + R_8}$

Putting in Component Values

$$E_o = -13.037 + \left(\frac{32.47 R_x}{R_1 + R_x} \right) \left(\frac{R_7}{R_6 + R_7 + R_1 \parallel R_x} \right)$$

So for Typical Case — S/N 005 AND 215K Shunt — we GET

<u>Temp</u>	<u>R_{Th}</u>	<u>E_o</u>
-40°C	31.3K	-6.89V
-45C	37K	-6.08V
-50C	47K	-5.15V
-55C	59K	-4.14V
-60C	75K	-3.06V
-65C	97K	-1.93V
-70C	128K	-0.79V
-75C	175K	+0.37V
-80C	250K	+1.49V
-85C	378K	+2.52V

So output Slope at Null

$$= \frac{\Delta V}{\Delta T} \approx \underline{\underline{-0.23V/^{\circ}C}}$$

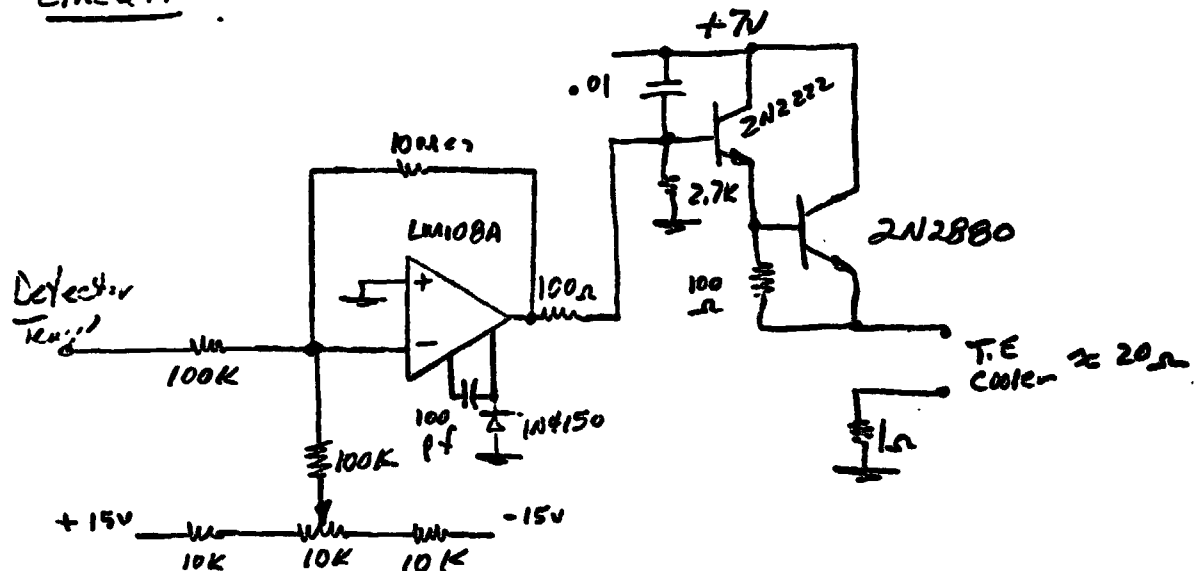
PROJECT
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T.E. Cooler Controller

DATE

10
OF

CIRCUIT



T.E. Cooler Drive

$$V_0 (e^{-70^{\circ}C}) \text{ typically} = 5.5V$$

$$So I_L = \frac{5.5}{20} = 280mA$$

we forced beta of 10 for 2N2880
and 15 for 2N2222

$$\text{current from LM108A needed is } \frac{280}{15} = 1.83 \text{ mA.}$$

So DRIVE CAPABILITY IS ADEQUATE.

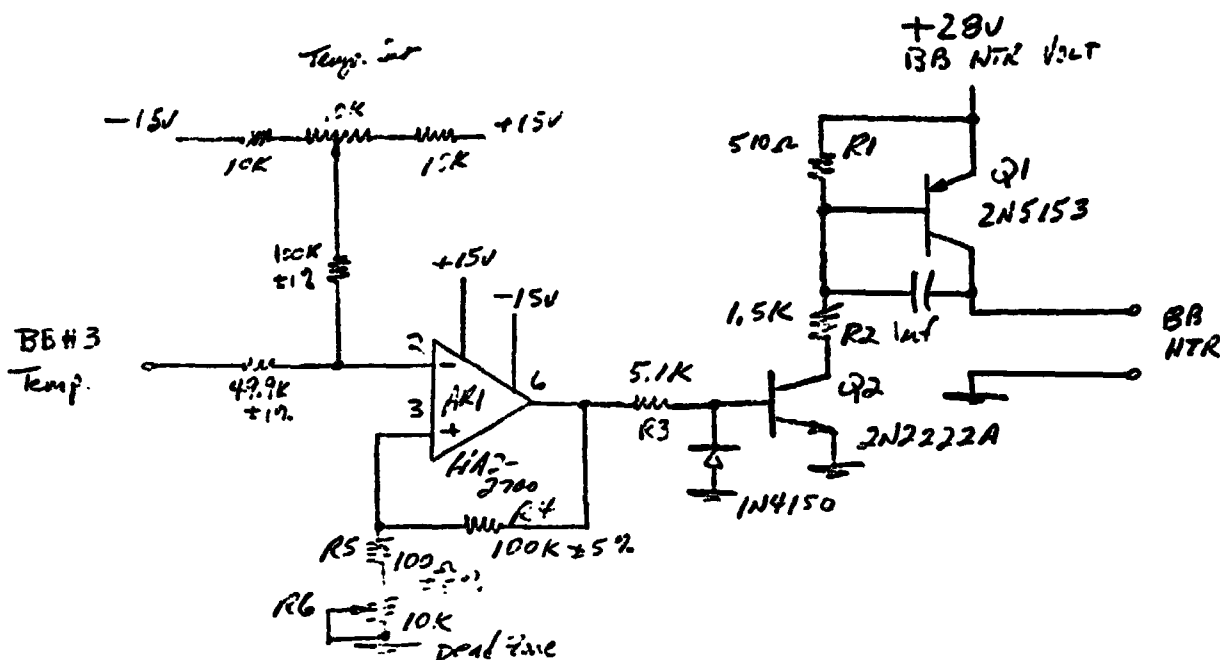
VOLTAGE COMPARISON Amplifier

$$V_{TE \text{ cooler}} = 100(V_{\text{Setpoint}} - V_{\text{Detector Temp}})$$

Since full scale drive is $\approx 6V$

Difference of Setpoint Voltage & Det. Voltage
is 0.06 volts which is $\approx 0.25^{\circ}C$

1. CIRCUIT



2) HEATER RESISTANCE

Power = 2watts MAX in Vacuum, EST. $\approx 5\omega$ in RA Kilo.
Heater Resistance = 78 OHMS

So with 28V Supply

$$Power\ to\ Load = \frac{E^2}{R} = 10watts$$

So controller should operate at $\approx 50\%$ duty cycle.

3) OUTPUT DRIVER CIRCUIT

$$I_{LOAD} = \frac{28V}{78\Omega} = 360mA$$

$$I_B(Q1) = \frac{28V - V_{CE}(Q1) - V_{SAT}(Q2)}{R_2} = \frac{28 - .9 - .25}{1.5(1.25)}$$

$$I_B = 14.32mA$$

$$\therefore \beta(Q1) \geq \frac{360}{14.32} \geq 25 \text{ is Required for Saturation of } Q1.$$

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SUBJECT

10A Temp Controller Circuit

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10/8/75

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OF

4) SN0222 DRIVE

$$\bar{I}_C = \frac{28 - V_{CE}(Q1) - V_{sat}}{1.5K(.75)} = \frac{28 - .7 - .05}{1.5K(.75)} = 21.37mA$$

$$\bar{I}_B(Q2) = \frac{V_B(R1) - V_{BE}(Q2)}{R3} = \frac{13 - .95}{5.1K(1.25)} = 1.91mA$$

$$\therefore \beta(Q2) \geq \frac{21.37}{1.91} \geq 11.21 \text{ is Required from } Q2.$$

5) MAX. ARI OUTPUT

$$I = \frac{15V - .6}{5.1K(1.15)} \leq 3.32mA \text{ WHICH THE HA2-2700 OP-AMP CAN SUPPLY.}$$

(b) Temperature Sense Comparator

(a) TRIP POINT = Zero \pm Hysteresis feedback

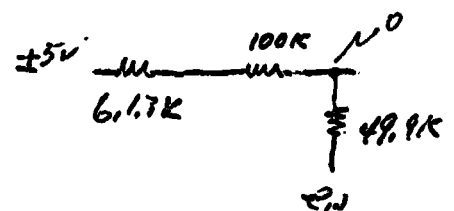
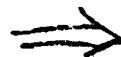
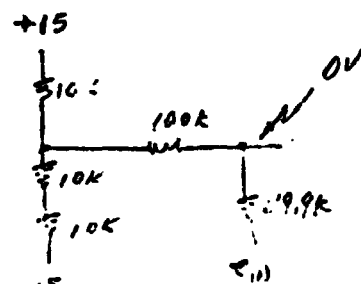
$$(b) \text{ Hysteresis} = \pm V_C \times \left(\frac{R5 + R6}{R4 + R5 + R6} \right)$$

$$\text{MAX} = \pm 14 \times \frac{10.1K}{110.1K} = \pm 1.28 \text{ VOLTS}$$

$$\text{MIN.} = \frac{\pm 14 \times .1K}{100.1K} = \pm 14 \text{ millivolts}$$

(c) MINIMUM/MAXIMUM E_{IN} Required for zero for different Setpoint Voltage

CASE #1



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ALPS

SUBJECT

BB TEMP Controller Circuit

DATE

10/8/75

(c) Continued

E_{IN} needed for Zero Volts at Comparator

$$\frac{\pm 5}{106.67K} = \frac{E_{IN}}{47.9K} \quad , \quad E_{IN} = \pm 2.34 \text{ Volts}$$

SINCE TEMP CRT output slope is $\approx 470 \text{ mV}/^\circ\text{C}$,

THIS $\approx \pm 5^\circ\text{C}$ ADJUSTMENT RANGE.

(d) MINIMUM Amplitude of Dead Zone referred to min:

$$\pm 14 \text{ mV} \times \frac{156K}{106K} = \pm 20.6 \text{ mV}$$

$$= \frac{20.6}{470} = \pm 0.05^\circ\text{C} \quad \text{OR} \quad 0.1^\circ\text{C dead zone minimum}$$

APPENDIX F

GROUND SUPPORT UNIT (G.S.U.)

**GROUND SUPPORT UNIT (G.S.U.)
FINAL REPORT**

**PREPARED BY
W. MORROW
T. V. WARD
BARRINGER RESEARCH LIMITED
304 CARLINGVIEW DRIVE
REXDALE, ONTARIO, CANADA**

**PREPARED FOR
T.R.W. SYSTEMS INC.
ONE SPACE PARK
LOS ANGELES, CALIFORNIA**

OUR REF: TR75-255

OCTOBER 1975

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G.S.U. Subsystem Tests Debugging and Calibration	5
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Shipping Document	18
Operational Manuals	

GROUND SUPPORT UNIT DESIGN AND FABRICATION

INTRODUCTION

The Ground Support Unit (GSU) was designed to serve as the radiometric calibration standard for the MAPS instrument and provides a capability for simulating a broad range of source temperatures and pollutant concentrations. It allows a complete end-to-end checkout and calibration of each MAPS channel. It was designed for use in the performance evaluation of the BRL brassboard interfaced with the TRW signal processor and prior to the redirection of the contract it had been intended to be used in the performance evaluation of all models through to the flight model. The GSU consists of a blackbody radiation source and absorption gas cell which may be adjusted over the temperature range 240°K to 320°K and placed between the target source and each individual MAPS channel.

COMPONENT DESIGN FEATURES

Blackbody Target Source

A blackbody source with a minimum clear aperture of 12 cms. was purchased from Eppley Laboratories. The source has an operating range of 240°K to 350°K , the lower temperature being achieved by a thermoelectric cooler backed by a Lauda Brinkmann refrigerator. The source is complete with five platinum resistance thermometer sensors which are capable of monitoring the uniformity and accuracy of the source to $\pm 0.1^{\circ}\text{C}$.

Absorption Gas Cell

The absorption gas cell consists of a type 304 stainless steel double walled cylinder of $\frac{1}{2}$ metre length between germanium windows. The cell has four ports, two for cell windows and one each for pressure and temperature feedthroughs, and pump and manifold couplings. Multiple circular baffles are located

between the double walls of the cell to restrict the coolant fluid flow, reduce any dead spaces within the volume, and remove any thermal non-uniformities within the cell. Nine copper-constantan thermocouples are located within the cell, three at each end and three located in the centre of the cell to measure thermal uniformity of the gas within the cell.

Cell Windows

Cell window material is germanium. Ge has transmission properties with broadband A.R. coatings > 90 percent required per window in each of the required spectral regions to achieve a cell transmission > 80 percent. It is also chemically compatible to small concentrations of the proposed test gases and its absorption coefficient does not change significantly over the temperature test range. The entrance window clear aperture is 12 cm. x 0.5 cm. thick and the exit window clear aperture is 9 cms. x 0.3 cm. thick. The A.R. coatings used have a vapour pressure < 10^{-3} Torr.

Pressure Transducer

An M.K.S. pressure transducer with a 0 to 1000 Torr head was initially installed in the absorption cell to act as the absolute standard for gas concentration measurements. However after delivery it was found that the M.K.S. capacitance manometer had insufficient accuracy and also suffered from considerable drift and could not be used as the absolute standard in the region 10^{-3} Torr - 1 Torr. To overcome this difficulty an NRC-801 thermocouple gauge was installed in the absorption cell and on the manifold to measure ultimate vacuum and leak rates. The calibration of the thermocouple gauges should be verified at regular intervals.

Vacuum Pump

A double stage rotary pump with a pumping speed of 100 litres/minute is used to evacuate the cell and manifold. With this pump in series with a molecular sieve trap an ultimate vacuum of 1×10^{-3} Torr was achieved in the absorption cell.

Heat Exchanger

An F.T.S. model FC-50-40 compressor with a Model P40 probe is used to provide the cooling capability to the circulating fluid between the cell walls. This combination with the probe immersed in an insulated, well stirred, open topped dewar containing 8 litres of ^{coolant} methanol and a room ambient of 24°C has a cooling capacity of ≈ 1200 Watts. A proportional thermocouple temperature controller with a 1.2 kw heater proportions power to the heater to achieve control accuracy of the fluid in the dewar of 0.1°C.

Thermocouple Readout

The nine thermocouples located within the absorption cell are read out on a Doric multi-channel digital thermometer with a resolution of 0.1°K.

Test Gas Specifications

Research grade test gases with certified analysis are used and introduced to the cell manifold via high purity stainless steel single stage regulators which have been helium leak tested.

The gases provided are as follows:

1. Matheson purity nitrogen with analysis for hydrocarbons and dew point.
2. 0.03 percent ammonia in nitrogen to a certified standard.
3. 0.3 percent carbon monoxide in nitrogen to a primary standard contained in an aged cylinder.

Insulation

The absorption cell is insulated with three inches of polyurethane foam to reduce the effect of conductive and convective heat losses when operating the cell at temperatures below ambient.

G.S.U. SUBSYSTEM TESTS

1. Inner Cell Leak Test July 8 to 14 -- see Figure 1A, 1B, 1C.
 - 1.1 The G.S.U. gas cell minus outer covering, port flanges and end flanges was leak tested with dummy flanges and ports. The cell pressure was monitored with a Varian 801 thermocouple gauge with 531 thermocouple head. Preliminary tests were carried out with the cell in the same condition as it was delivered from the welder, that is with the welding blemishes from the attachment of the circulation baffles. These tests indicated that the cell leak plus outgassing rate was 7 ± 1 μ /minute. In addition negative results were obtained (indicating no leaks) when the cell welds were sprayed with acetone.
 - 1.2 After this test the decision was made to grind out the weld blemishes since they obstructed the placement of the T.C. rack and were potential sources of outgassing. After the welds were ground out the cell was cleaned of any loose metal and flushed with tetrachloroethylene until no residue appeared on a clean kimwipe used to scrub the inner cell wall.
 - 1.3 The second inner cell vacuum test proceeded as the first. The leak plus outgassing rate was approximately 3 μ /minute and the acetone spray gave negative results. The leak and outgassing rate was approximately .4 that of the preceeding test (1.1). This indicated that cleaning the cell inner walls and/or removing the weld blemishes reduced outgassing. The cell exceeded the leak specifications (20 μ /minute) by a factor of 7 times and was cleared for welding the flanges, ports and outer shell.
2. Checkout of the MKS Capacitance Manometer. May 30 to June 3.

2.1 In order to test the MKS system, the pressure head was attached to a rotary pump vacuum system to which a Varian thermocouple head and Vacustat McLeod gauge were also attached. Pressure readings were taken with the pump valve closed so that all gauges were at the same pressure during the test. Two sets of measurements were made; one set was made three hours after switching on the electronics and the second was made three days after switch on (the latter set was taken to ensure that measurements were taken after the system had adequate time to thermally stabilize).

2.2 Friday Observation (May 30) -- see Figure 2.

The MKS capacitance manometer system exhibited zero drift that exceeded the absolute pressure accuracy specification of 10^{-5} of full range which was 1,000 Torr. The drift observed was positive and exceeded 1.0 Torr/hour. The drift measurements were made after the manometer and associated electronics had warmed up for two hours (with the manometer thermal regulator on). The quad setting had been minimized and the null and full scale calibrations had been set. The system pressure was verified not to drift by checking with a McLeod gauge and a Varian thermocouple gauge, both of which gave the same absolute pressure to within $\pm 5 \mu$ with no indication of pressure drift.

2.3 Monday and Tuesday Observation (June 2 and 3) -- see Figure 3.

The MKS manometer was run on the vacuum system over the weekend (the system pressure was unchanged Monday morning at 40 μ). The MKS zero was set at 40 μ and the pressure monitored for 24 hours. The manometer showed an initial drift of -.02 Torr/hour which was reasonably linear. In addition the MKS pressure reading fell to -.57 Torr overnight (net rate of 0.1 Torr/hour).

2.4 On the basis of these measurements the MKS head was returned for replacement.

3. Checkout of Replacement MKS Head and Pressure System (July 14)

- 3.1 After receipt of the MKS replacement head a second calibration test was carried out. MKS again had not supplied a calibration for the head in the 0 to 1000 Torr region (as requested by BRL). Communication with MKS indicated that no systematic calibration in the region had been taken and time constraints did not allow the head to be returned to MKS for calibration.
- 3.2 The MKS head was attached to the Alcatel vacuum pump and pumped down. The DVM (170 - M - 25) readout for the MKS head read 12 V overload with the electronic setting on null (0.0 V output), F.S. (10.0 V output) and with the DVM inputs noted. Operation of the MKS head and electronics (minus the DVM) was verified with an AVO meter. A replacement DVM was requested (shipped from MKS on July 14). The rest of the MKS system was checked out with an H.P. DVM and with a McLeod and Varian pressure head to calibrate the MKS head.
- 3.3 After the system pressure had stabilized (both on the Varian thermocouple and the McLeod) the MKS showed a negative pressure drift. The MKS, Varian and McLeod pressure readings were monitored for a 15 hour period. The Varian and McLeod readings remained stable at 50 μ and 40 μ respectively during the 15 hour interval. The MKS pressure reading decayed from 1450 μ to -200 μ during the same interval falling most rapidly in the first two hours (e.g. 1450 to 135 μ). See Figure 4.
- 3.4 Communication with MKS indicated that the system performance was generally measured after stabilization for at least 3 hours. The "absolute" accuracy statements in the MKS literature were concluded to be valid for only short term measurements. Our test indicated absolute pressure measurements have an accuracy no greater than ± 2 Torr unless calibrated with another absolute pressure head.

4. Vacuum Pump Checkout (July 13)

The McLeod pressure gauge was connected directly to the Alcatel vacuum pump. The ultimate vacuum obtained for the pump (without the molecular sieve) was measured at 1.4μ . McLeod gauges of this type have absolute accuracies of $\pm 3\mu^*$ (Ref. Edwards vacuum components catalogue pp. 111, 112).

(* at pressure from 10μ to 0μ)

5. Checkout of Varian TC Gauge (July 16)

- 5.1 The Varian TC gauge and the McLeod gauge were attached to the Alcatel vacuum pump (with molecular sieve). One half hour after the pump down the Varian thermocouple gauge read 30μ while the McLeod gauge read 5μ . The Varian thermocouple pressure reading then slowly fell while the McLeod remained at 5μ . After about 10 hours the Varian stabilized at 10μ (McLeod read 5μ). The Varian gauge reading remained at 10μ for about 5 hours (until the system was pressurized).

Subsequent measurements with the Varian thermocouple gauge confirmed their zero drift. In order to obtain an accurate pressure zero with the Varian pressure gauge it should be held at a vacuum that is better than 10μ for at least 10 hours.

6. Checkout of Blackbody System (July 22). See Figure 5, 6.

- 6.1 The blackbody system was interconnected per the Eppley instructions. Operation of the Doric platinum resistance thermometer was verified at room temperature. The platinum resistance thermometers read room temperature to within $.2^{\circ}\text{C}$ (no control on BB temperature).
- 6.2 The Lauda Brinkman cooler was set at -10°C and the compressor was switched on. After 1 hour 45 minutes the temperature of the bath (with circulation pump off and no thermal load) read $+10^{\circ}\text{C}$. The circulation pump was switched on and the blackbody T.E. cooler was set at 1,000 (low range). The BB temperature fell to -40° and then began to rise. The coolant temperature rose from 10°C to 25°C . It was apparent that the T.E. cooler was thermally overloading the Lauda Brinkman cooler.
- 6.3 The test was repeated with the T.E. cooler at a setting of 2,500. In this test the BB temperature reached -20°C then began to rise when the coolant temperature went from $+14.5^{\circ}\text{C}$ to about 35°C .
- 6.4 It was concluded that the Lauda Brinkman cooler could not handle the 150 watt maximum thermal load of the blackbody T.E. cooler. The rated cooling power of the Super K2R cooler was 250 watts. Consequently, efforts were made to have the refrigerator unit repaired or replaced.

7. Vacuum Test of the Completed Cell (July 23 to July 25. See Figure 7.

- 7.1 The completed cell (with end flanges, port flanges and outer shell) was connected to the Alcatel vacuum pump with molecular sieve. The Varian thermocouple, McLeod, and MKS pressure gauge were connected to the inlet of the pump upstream of the gate valve with a "Tee" coupling. The upper flange was sealed with the doubler flange, germanium window, and window retaining ring (per assembly drawing). The lower flange was sealed with a flat plate and "O" ring.
- 7.2 The system was pumped down and the pressure read on the Varian thermocouple and the McLeod gauges. The cell pumped to 10μ in about 5 minutes and to about 5μ in one hour.
- 7.3 The main gate valve was closed and the pressure monitored with time. The Leak plus outgassing rate with the McLeod was $3.1\mu/\text{minute}$, with the Varian thermocouple, $13\mu/\text{minute}$ and with the MKS, $3.8\mu/\text{minute}$. The MKS rate was measured by the decrease in pressure when the system was pumped out (after being closed off 10 minutes). In this way the drift of the MKS did not affect the reading because the pump out occurred in less than 10 seconds.

The difference in readings between the McLeod, MKS and the Varian indicated that the Varian was more sensitive to an outgassed component than either of the displacement type gauges. This is not unusual since the Varian is sensitive to the thermal conductivity of the medium surrounding the gauge, which changes with molecular weight as well as pressure.

- 7.4 All welds on the cell were sprayed with acetone while the system was under vacuum (gate valve closed) and no leaks were detected.

8. Vacuum Test of Completed Cell Coolant Chamber. July 28. See Figure 8.

The coolant chamber was connected to the vacuum pump with flexible teflon tubing. The inner chamber was pressurized and the window was removed. The outer chamber pumped down to 30 μ on the McLeod gauge. All welds on the outside and the inside of the cell were tested by spraying with acetone. No leaks were detected in the coolant chamber.

9. Checkout of Brinkman Lauda Cooler after "Repair"

The Lauda Brinkman cooler was set at -20°C and the compressor switched on. The temperature of the coolant in the bath was monitored (circulator on, T.E. cooler off) with time. The temperature of the bath fell to $+15^{\circ}\text{C}$ (from 27°C) in 31 minutes, then began to rise. The thermal overload relay on the compressor motor began switching at the point in time that the bath began to warm up. The problem was diagnosed as either a faulty thermal overload switch or a faulty compressor motor that caused the system to overheat. Communications were resumed with Brinkman and Eppley in order to have the system replaced or repaired.

10. Checkout of the FTS Temperature Control System

The FTS bath was filled with methanol and water solution and the compressor, pump and stirrer were hooked up. The stirrer and pump operations were verified. The compressor motor operated intermittently when connected to the mains with an extension cord. Checking the voltage across the cord indicated that the starting current of the compressor caused an 18V drop when the compressor was switched on. The compressor operated satisfactorily when connected directly to the mains through its own power cord. The system achieved a bath temperature of -32.5° in $1\frac{1}{2}$ hours when the ambient temperature was $+32.22$ ($\Delta T = 64.7^{\circ}\text{C}$).

11. GSU Debugging and Calibration

11.1 Calibration of Gas Cell Thermocouple

The nine Omega thermocouples to be used in the gas cell were interconnected with the Doric Digital Thermocouple readout per Doric instructions. The ends of the thermocouple were sheathed in plastic and attached to the Lauda Brinkman cooler bath thermometer, near the bulb. After a preliminary calibration run the Doric zero and span controls were set so that the Doric readout corresponded to the Lauda Brinkman thermometer. The bath was then cycled from -5.4°C to $+49.2^{\circ}\text{C}$ in a one hour period. Readings were taken for all nine thermocouples at eight temperatures. See Table 1. At the highest temperature the potential across thermocouple #5 and #6 (#6 in water ice bath) was measured. Thermocouple #5 was supplied with an absolute calibration carried out by Orenda. The voltage across these thermocouples corresponded to 54.33°C compared to an average reading of 54.41°C for the rest of the thermocouples. Thus the maximum error in absolute temperature (at 54.40) is estimated at $.08^{\circ}\text{C}$.

L.B. Thermo- meter	T/C 1	T/C 2	T/C 3	T/C 4	T/C 5	T/C 6	T/C 7	T/C 8	T/C 9	
-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	°C
-1.1	-1.1	-1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	"
+2.8	2.8	2.8	2.8	2.7	2.7	2.7	2.7	2.7	2.7	"
+10.8	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.6	10.6	"
24.1	24.0	24.0	24.0	24.0	23.9	24.0	24.0	24.0	23.9	"
25.3	25.2	25.2	25.2	25.2	25.2	25.2	25.3	25.3	25.2	"
36.5	36.5	36.5	36.5	36.4	36.4	36.5	36.5	36.5	36.5	"
49.2	49.3	49.3	49.2	49.2	49.2	49.2	49.3	49.2	49.2	"

TABLE 1.

11.2 Debugging Vacuum System

The assembled vacuum system was tested in the following sequence:

1. Vacuum pump to ACG valve and $\frac{1}{4}$ " shroud and manifold pumpline
2. Vacuum pump to manifold and shroud gate valve
3. Manifold
4. Shroud pumpline
5. Gas cell
5. Black Body shroud

Each subsystem was tested by spraying couplings, joints and valves with acetone. In addition ultimate vacuums and leak plus outgassing rates were measured (where possible). Only minor leaks were detected and these were eliminated by tightening the vacuum couplings. The molecular sieve filter was found to outgass but this was remedied by replacing the charge of the molecular sieve. The vacuum pumpline (1) (2) pumped down to 6μ in 15 minutes and fell to about 2μ in three hours. The manifold and shroud pumpline (3) (4) had a leak plus outgassing rate of $2\mu/\text{minute}$ and pumped down to 25μ (on the manifold thermocouple pressure gauge) after 16 hours. The gas cell had an outgassing rate (after 48 hours of continuous pumping) of $1.5\mu/\text{minute}$ and an ultimate vacuum (by thermocouple pressure gauge) of 1.3μ . The blackbody shroud reached 280μ in about three hours.

11.3 Debugging Cell Fluid Circulating System

The Cell circulation chamber was filled with fluid by venting with the plug at the top of the cell with the FTS circulation pump running. The fluid level of the bath was monitored for 72 hours after this to detect any leaks into the fluid circuit (cell, pipeline, pipeline connections) which would have resulted in an increase in the bath level. No increase of the bath level was detected.

11.4 Debugging Replacement Blackbody Cooler

The replacement Lauda Brinkman cooler was connected to the blackbody. The bath was charged with methanol and the compressor run (with the

11.4 (Continued)

the circulation pump off) until the bath temperature was -20°C (1½ hours). The circulator was then switched on. The Black Body temperature fell to -12°C in about one hour. The Temptonic T.E. control was set at 2,000 and switched on. The Black Body temperature fell to -41°C in 8 minutes. The T.E. control was reset to 2,350 and the BB temperature stabilized at $40.0^{\circ} \pm .1^{\circ}\text{C}$ for two hours. In this time the coolant temperature rose to about -9.5°C . See Table II.

Table II

Elapsed time after TE cooler switched on (minutes)	$^{\circ}\text{C}$ Black Body Temperature	$^{\circ}\text{C}$ Coolant Temperature
0	-12	-19
2	-26	-17.5
5	-36	-15
8	-41	-13.5
13*	-40	-13.0
43	-39.9	-12
114	-40.06	-10
133	-40.10	-9.5
*reset TE control to 2,350		

ACCEPTANCE TESTS

Formal Acceptance Tests were carried out on the G.S.U. at BRL premises on September 4th and 5h, 1975. These tests were carried out in the presence of BRL Q.A. personnel and a TRW representative. The test data recorded are included.

SHIPPING

A copy of the shipping order for the G.S.U. is included. A BRL representative was on hand at TRW to assemble the GSU after receipt of shipment at TRW. This was accomplished and all systems checked out to TRW satisfaction.

QUALITY ASSURANCE

The document package assembled by Quality Assurance for 196-11 GSU is on file, and is to all intents and purposes structured in the following manner.

1. The Receiving Function

Copies of Purchase Orders, Packaging Slips, Drill Certificates, Test Result Sheets, Certificates of Compliance and all related correspondence together with BRL Accept, Test and/or Reject Tags are cross referenced completely and recorded in an "Incoming Materials Log", such log allocating R/L (Release Numbers) that act as common demonimations to individual incoming occurrences.

2. Assembly and Internal Manufacture

All work tasks performanced internally are qualified by Q.A. acceptance tags, all such tags having been retrieved and assembled in the Q.A. files.

3. Correspondence BRL/TRW

Copies of all correspondence by BRL and by TRW related to Quality Assurance remain on Q.A. files.

4. GSU Acceptance

Copies of all acceptance test and test data information are on Q.A. files, as yet we still await return from TRW signed copies of the formal acceptance test document and the IR 501108 that will "buy off" the deviations from specifica

ORIGINAL PAGE IS
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BARRINGER RESEARCH

BARRINGER RESEARCH LIMITED
394 CAVLINGVIEW DRIVE
METROPOLITAN TORONTO
REXDALE, ONTARIO
CANADA M9W 5G2
PHONE: 416-677-2491
CABLE: BARESEAPCH
TELEX: 06-948743

TEST DATA SHEET

1 / 2

JOB NO.

196-11

DRG: 5805800

REV'n Orig.

DESCRIPTION

G. S. U.

CHARACTERISTIC	SPECIFICATION	ACTUAL MEASURED	TIME etc.	REMARKS
PARA. 1.1.1.	$\leq 5 \times 10^{-3}$ TORR	5. MICRONS.		
1.1.2.	20 TORR \pm 2 TORR	✓		
1.1.3.	100 TORR \pm 5 TORR	✓		
1.1.4.	1000 TORR \pm 20 TORR	✓		
PARA. 1.2.1.	5×10^{-3} TORR in ≤ 10 Min.	4 MINUTES.	4-32-15 4-36-15	BASED ON MELED D GAUGE READING.
PARA. 1.3.1.	2×10^{-2} TORR/Minute	$.65 \times 10^{-2}$ TORR/MIN.		
PARA. 1.4.1.	≤ 2400 K	248°K.		OUT OF SPEC. SEE INSPECTION REPORT IL 50110
1.4.2.	≥ 3200 K	324.25°K.		
PARA. 1.5.3.	≤ 100 Minutes			NOT CARRIED OUT DUE TO TIME RESTRICTION.
1.5.5.	≤ 100 Minutes			
1.5.7.	in ≤ 100 Min.			
PARA. 1.6.3.	3200 K ± 50 K	324.25°K.		
1.6.4.	$\leq \pm 10$ K	✓		

TEST SPEC./PROC.

TESTED BY

DATE

ACCEPTED BY Q.A.

DATE

BRL 6012
REV: A

J. V. K. K. K.

F-24

SEPT 5/75.

BAL
R. G. K.

T. K. W.

SEPT 5/75.



BARRINGER RESEARCH LIMITED
304 CAPPINGVIEW DRIVE
METROPOLITAN TORONTO
REXDALE, ONTARIO
CANADA M9W 5G7
PHONE: 416 677 7491
CABLE: BAPSEAPCH
TELEX: 06-961743

TEST DATA SHEET

2 / 2

JOB NO.

196-11

DRG: 5805800 REV'n Orig. DESCRIPTION G S U

CHARACTERISTIC	SPECIFICATION	ACTUAL MEASURED	TIME etc.	REMARKS
PARA. 1.7.4.	$\leq \pm 2.5^{\circ}K$	✓		
PARA. 1.8.2	50cm \pm 0.1cm	50.10 cm		
PARA. 1.9.2.	2.2×10^{-2} TORR/min.	0.43×10^{-2} TORR/min.		
PARA. 1.10.2.	Maintain ≤ 1 TORR	✓		
PARA. 2.1.1.	$\leq 240^{\circ}K$	232°K		STABILITY MEASURED LESS THAN $\pm 1^{\circ}$ IN 15 MINS.
2.1.2.	$\geq 350^{\circ}K$	353-8°K		
PARA. 2.2.4.	$\leq \pm 0.1^{\circ}K$	$\pm 0.08^{\circ}K$		
PARA. 2.3.4.	$\leq \pm 0.1^{\circ}K$	✓		
PARA. 2.4.3.	<60 Minutes	279.15°K. 13 MINUTES.	09:32 09:45	
PARA. 2.5.2.	Maintain ≤ 1 TORR			NEGATED - SHROUD TEST. AT 1.10.2. WITH BLACK BOD IN PLACE.

TEST SPEC. PROC.	TESTED BY	DATE	ACCEPTED by Q.A.	DATE
BRL 6012	A. J. Ward	SEPT 5/75	BRL / T.R.V.	SEPT 5/75

REV: K

F-25

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**BARRINGER RESEARCH LIMITED,
TORONTO, ONT., CANADA**

INSPECTION REPORT

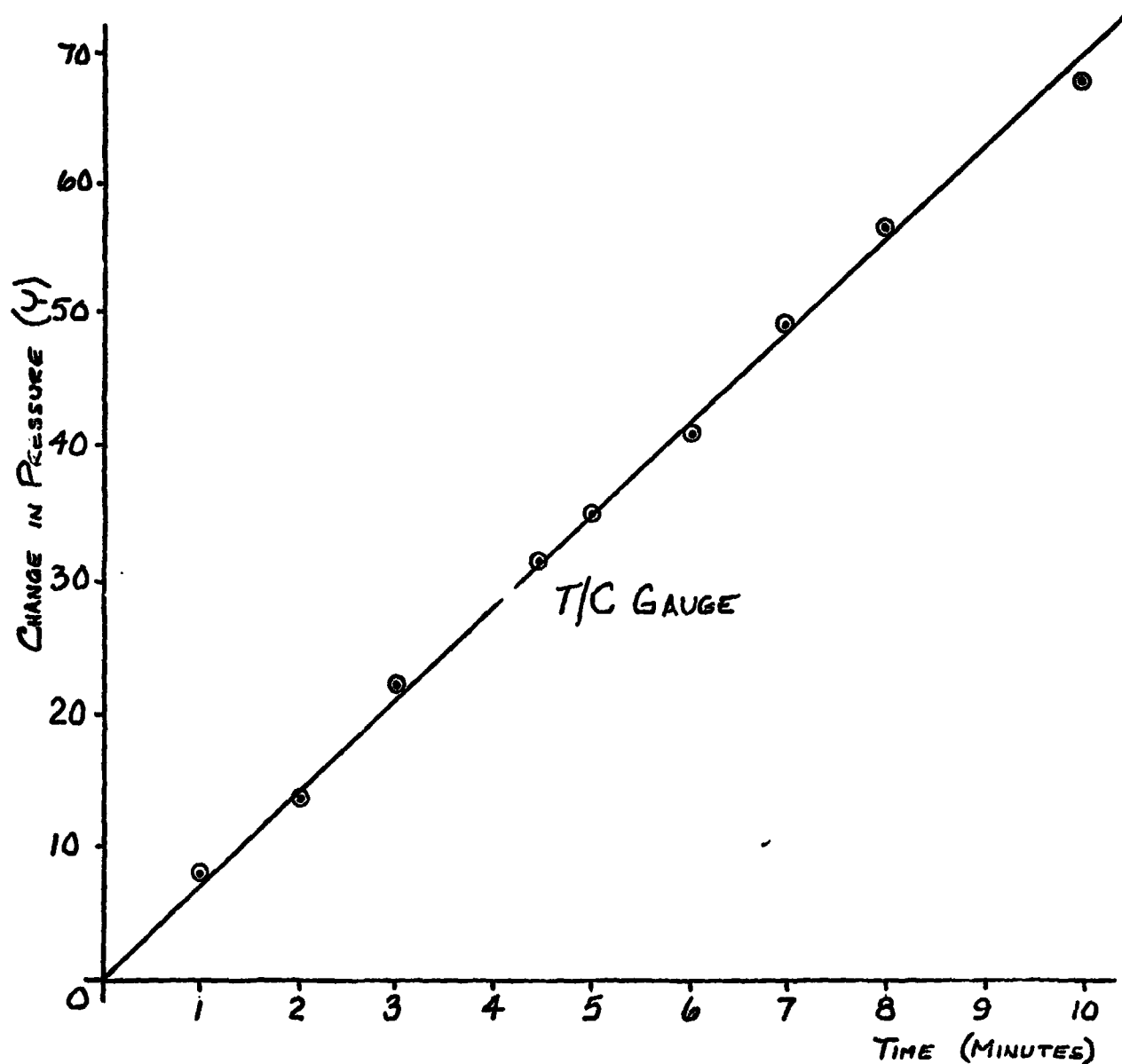
JOB NO.		I.R. <u>501108</u>		
DWG/PART NO. <u>196-11.</u>	P.O. SUFFIX <u>N/A.</u>	DATE <u>SEPT 5th/75</u>		
DWG/PART NO. <u>5805800.</u>	DESCRIPTION <u>G.S.U. ACCEPTANCE TEST</u>	VENUE/INTERNAL <u>Q.A. ACCEPTANCE TEST.</u>		
QTY. ACCEPT <u>/</u>	QTY. MADE <u>1</u>	DISCREPANCY		
<p>Ⓐ CHARACTERISTIC AT PARA. 1.4.1. DOES NOT MEET SPEC^N ACTUAL MEASURED <u>248°K.</u> SPEC^N = <u>≤ 240°K.</u></p> <p>Ⓑ TESTS AT PARAS 1.5.3. - 1.5.5. & 1.5.7. NOT COMPLETED.</p>				
REJECT <u>1</u>		INSPECTOR <u>R.G. Hacterson</u>	STAMP	
ACTION: <u>BRL recommend (based on TRW Customer discussions) That this unit be shipped "As Is". BRL will supply two gaskets which should aid in meeting 1.4.1 during future tests at TRW. V/H Reich</u>				
SCRAP	ACCEPT AFTER REWORK	INSPECTOR	QTY.	
SPECIAL INSTRUCTIONS:		M.R.D. APPROVAL		
		SIGNING AUTHORITY	PRODUCTION SUP'V'R. <u>JH Davies</u>	QTY.
			PROJECT SUP'V'R. <u>V/H Reich</u>	
			Q.A. SUP'V'R. <u>R.G. Hacterson</u>	
			CUSTOMER REP.	
TOTAL		TOTAL		
SCRAP		ACCEPT		

REF: BRL 6012 REV. A

OPERATIONAL MANUALS

1. Eppley - delivered to TRW with GSU
2. Lauda - included in this package
3. MKS - delivered to TRW with GSU
4. NRC - included in this package
5. FTS - delivered to TRW with GSU
6. Doric - delivered to TRW with GSU
7. BRL - included in this package

Fig. 1A

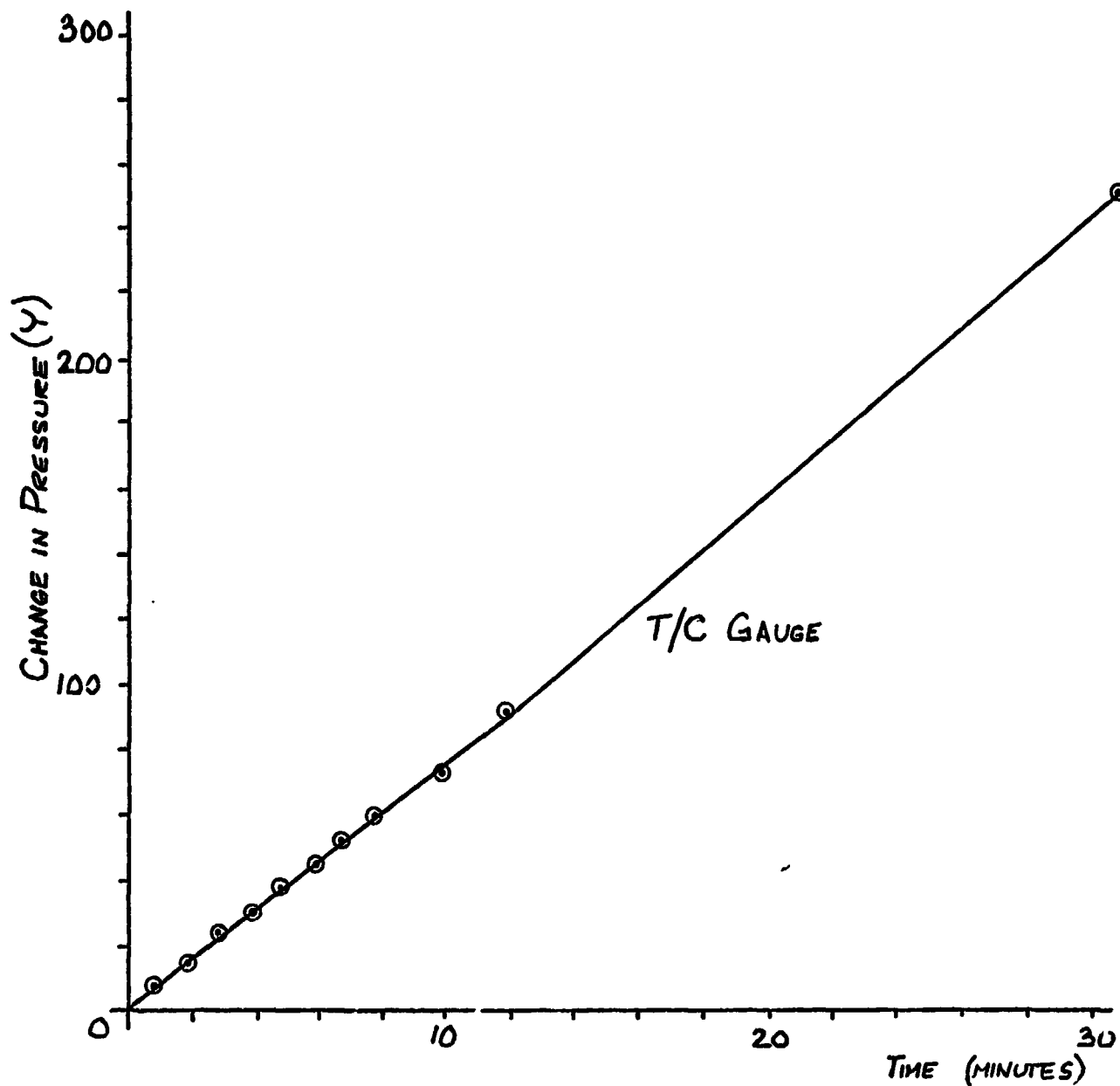


GSU INNER CELL VACUUM LEAK TEST
(PRIOR TO CELL CLEAROUT)

JULY 8th 1975

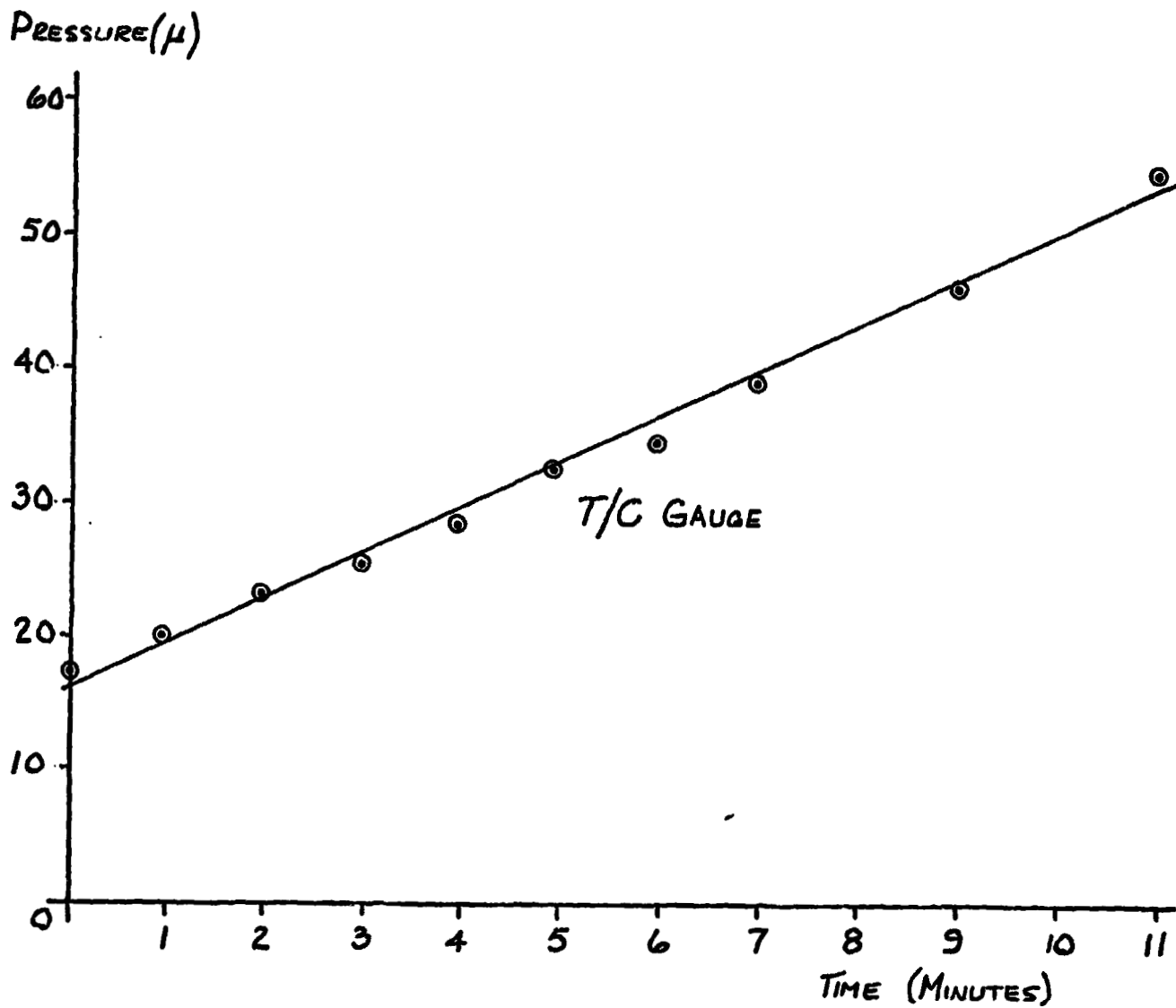
PRESSURE RISE AT 74/MIN

Fig. 1B



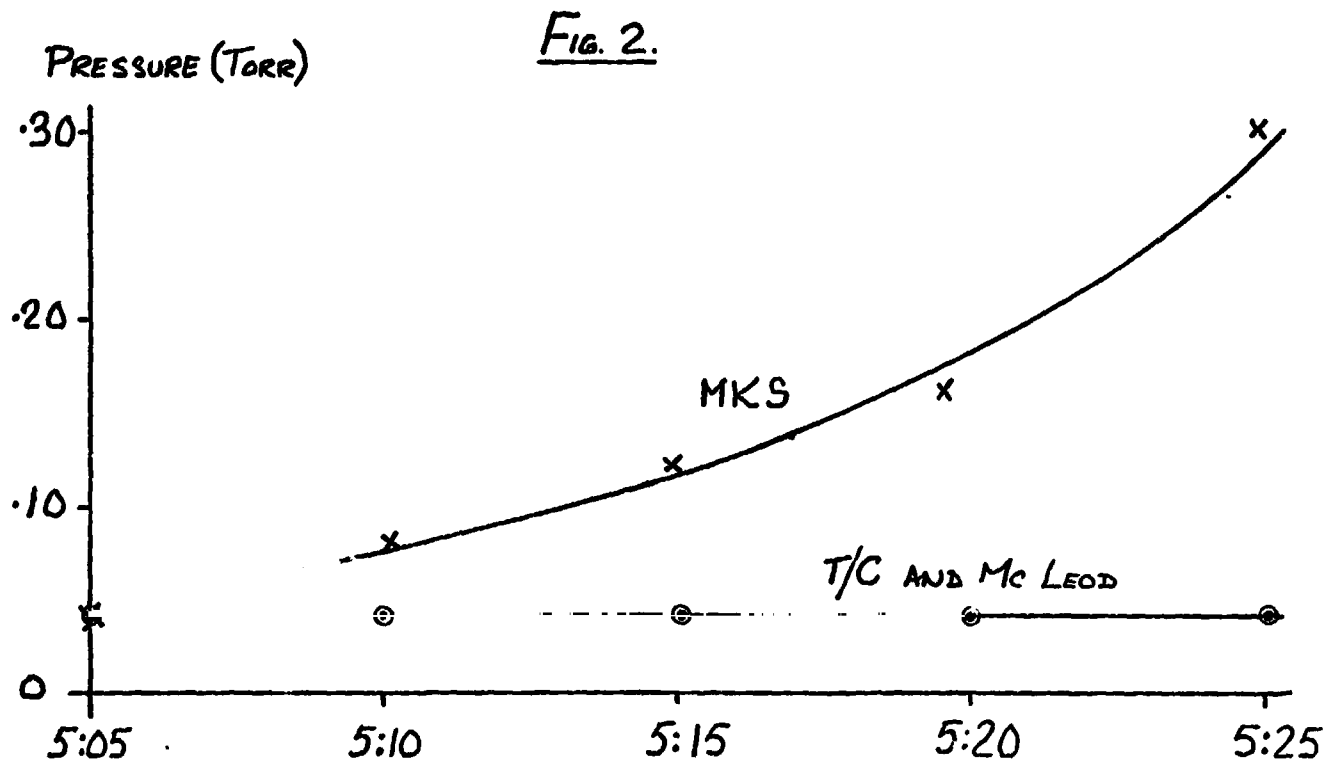
GSU INNER CELL VACUUM LEAK TEST
(PRIOR TO CELL CLEAROUT)
JULY 8th 1975

Fig. 1C

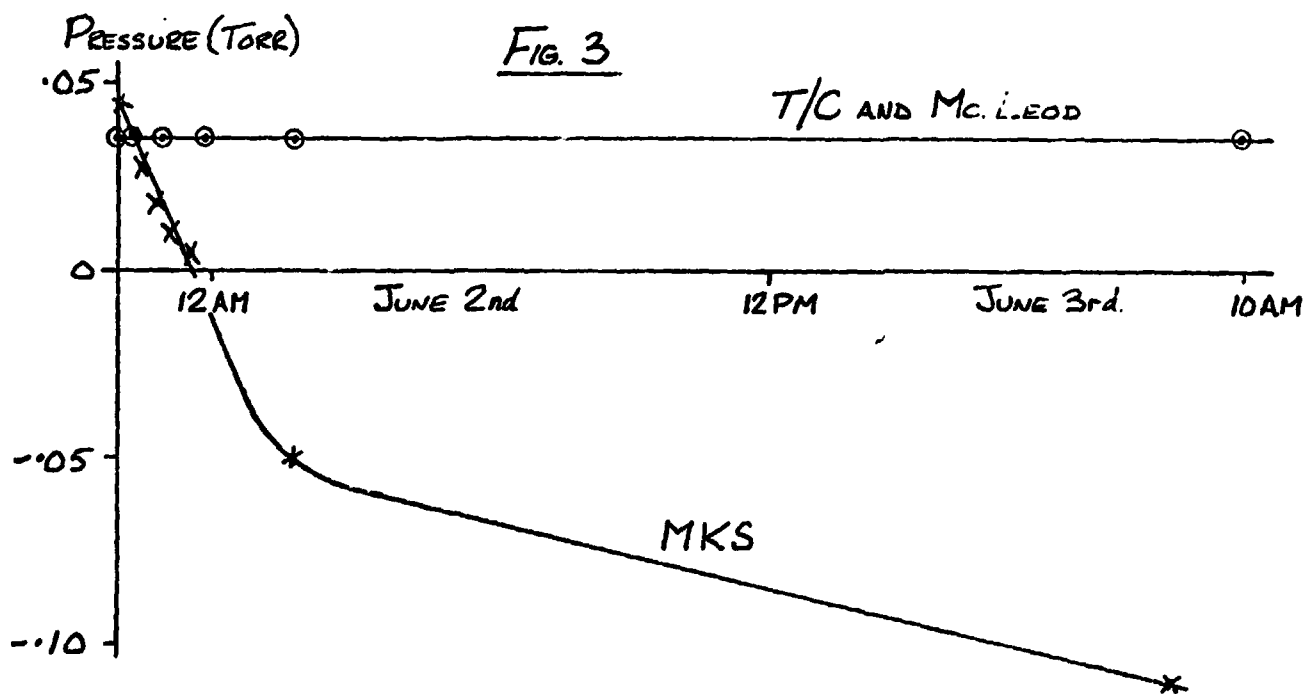


GSU INNER CELL VACUUM LEAK TEST
(AFTER CELL CLEAROUT)

PRESSURE RISE $3.3 \mu/\text{MIN}$

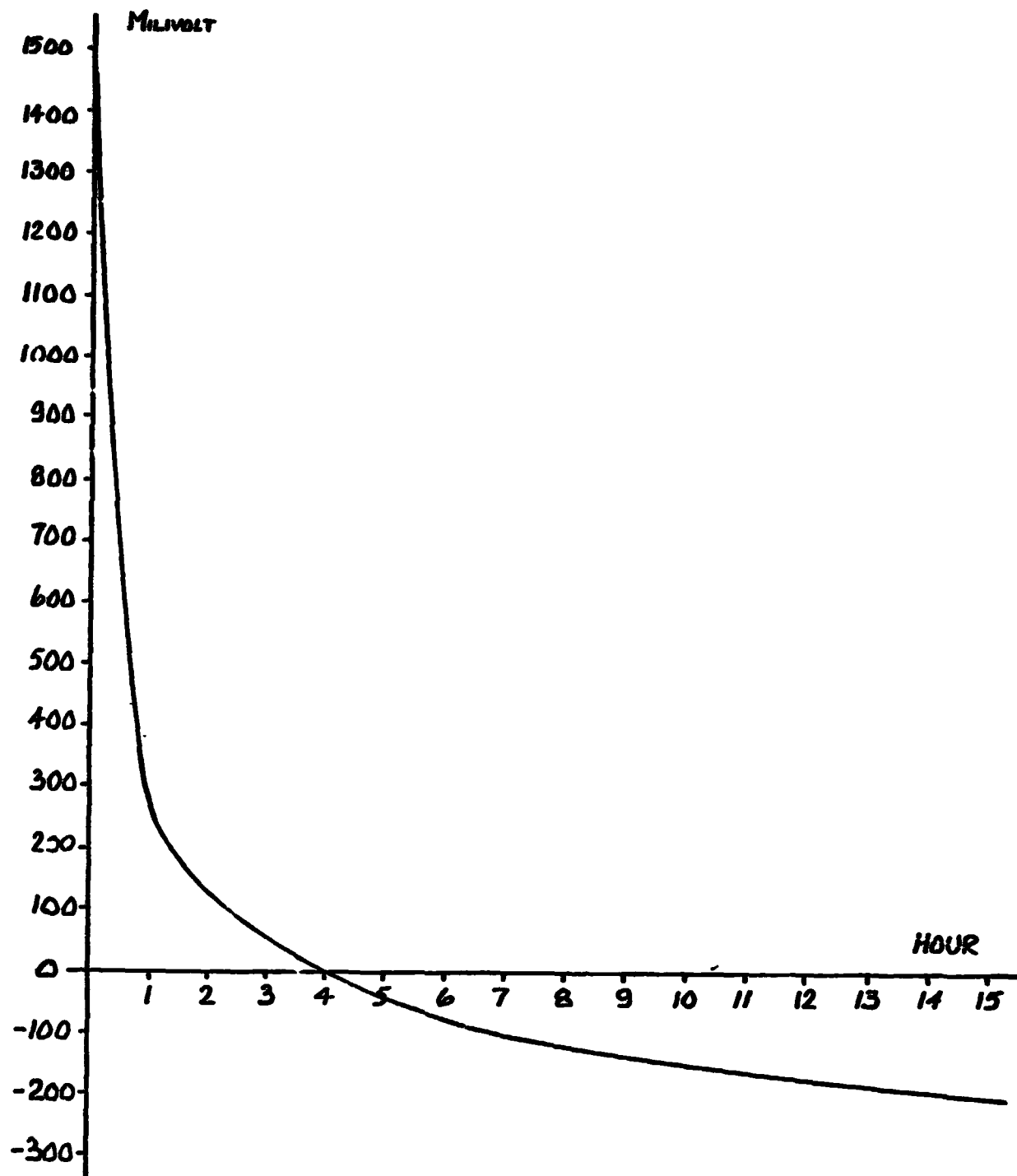


ZERO DRIFT ON MKS PRESSURE TRANSDUCER
AFTER 3HR WARM UP



ZERO DRIFT ON MKS PRESSURE TRANSDUCER
AFTER 3 DAY WARM UP

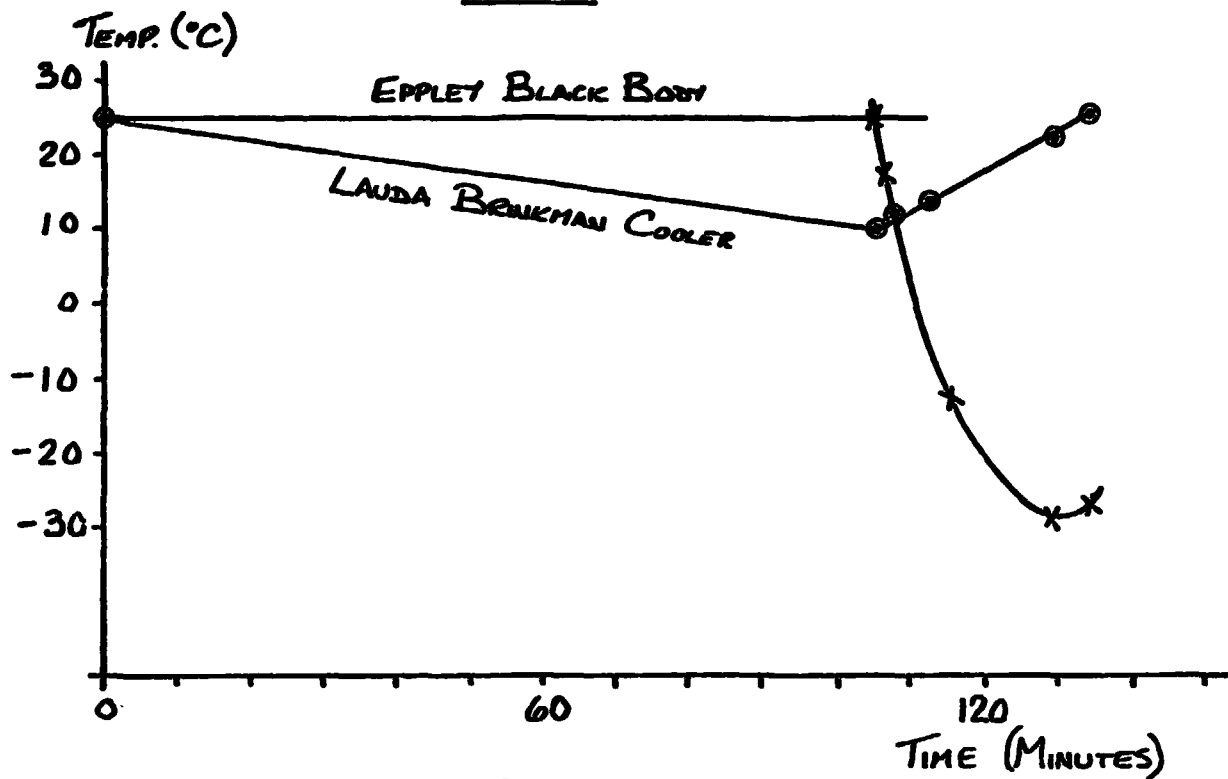
Fig. 4



1000 mV = 1 TORR

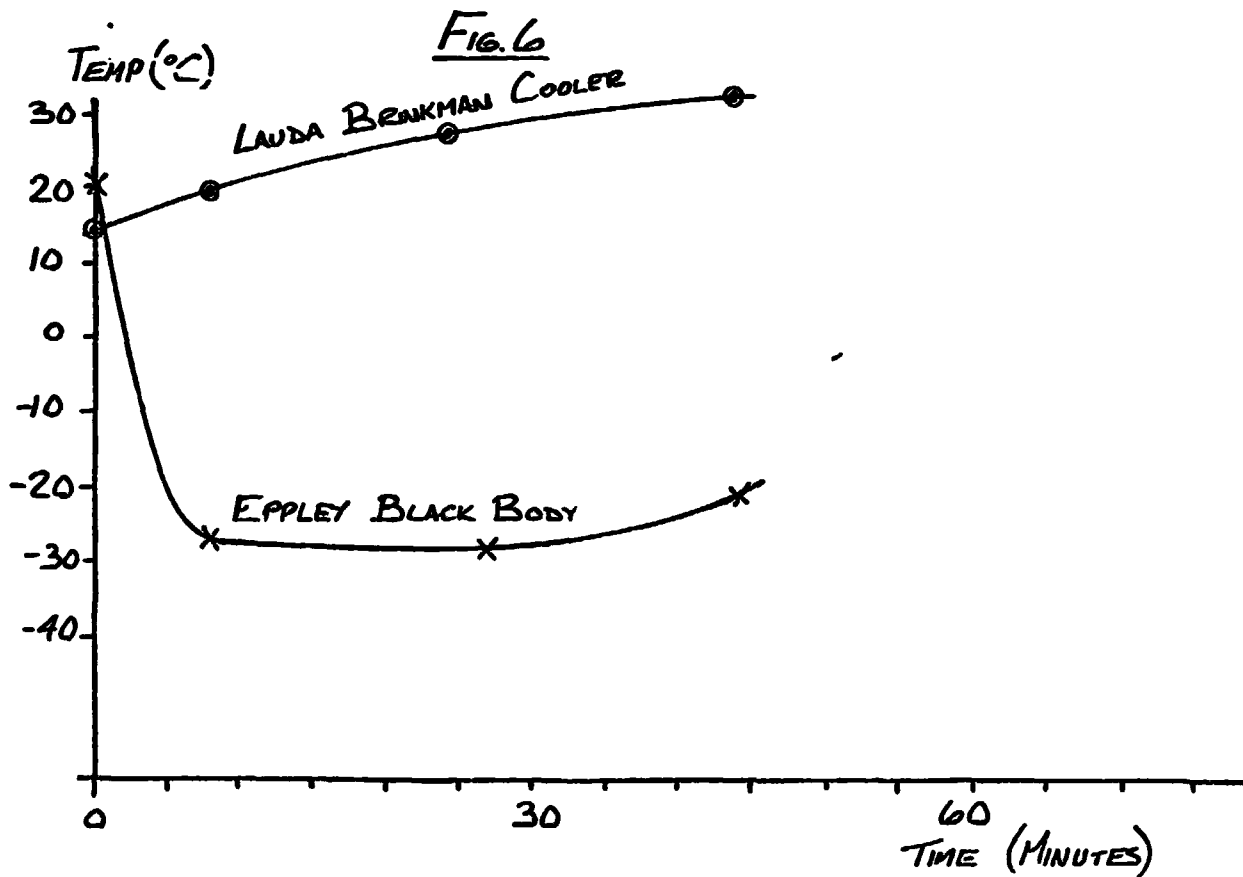
MKS SENSOR HEAD
TYPE 310 BHS-1000 SER. No. 13426
ZERO DRIFT

FIG. 5



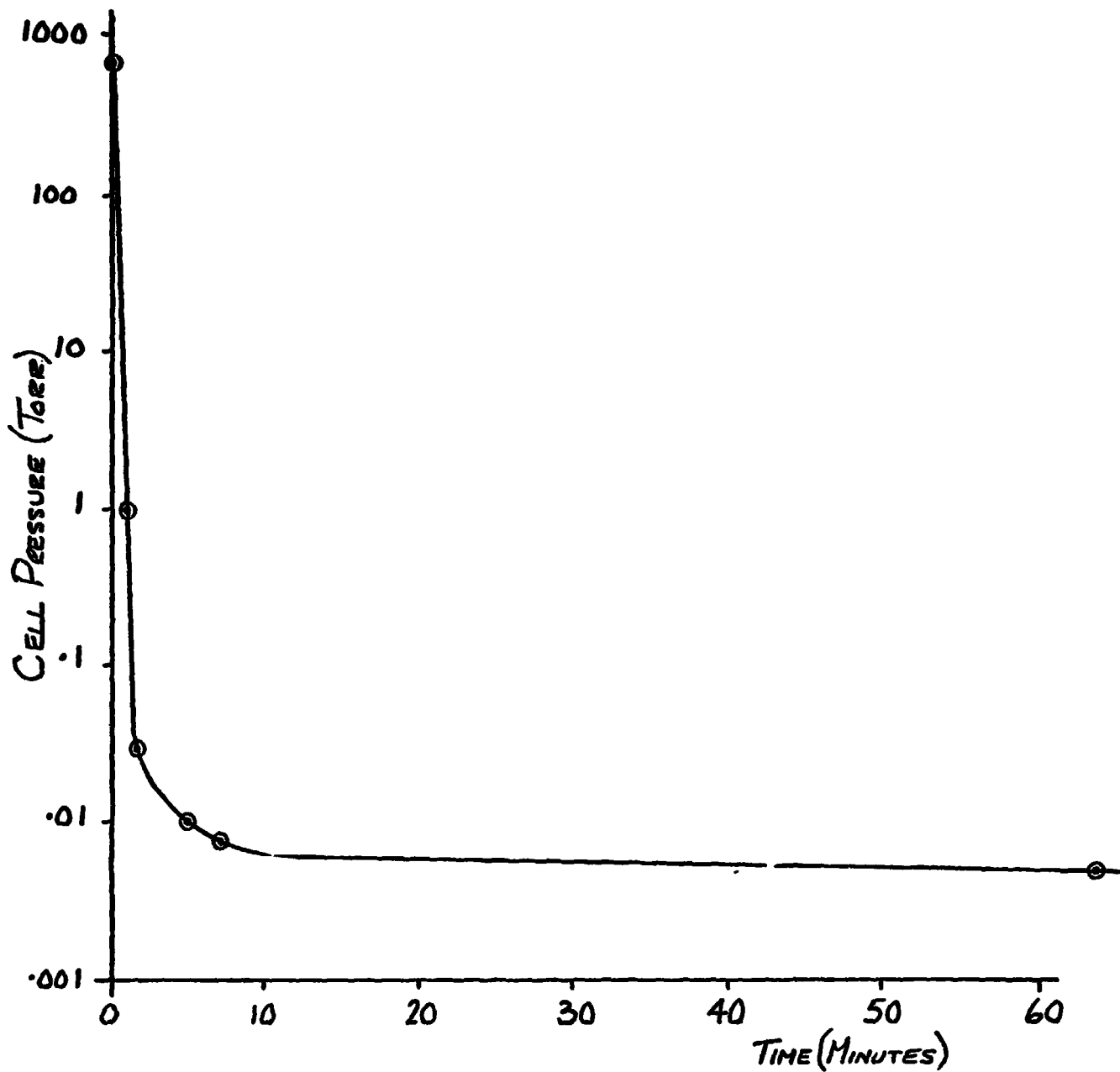
T.E. SET AT 1,000

FIG. 6



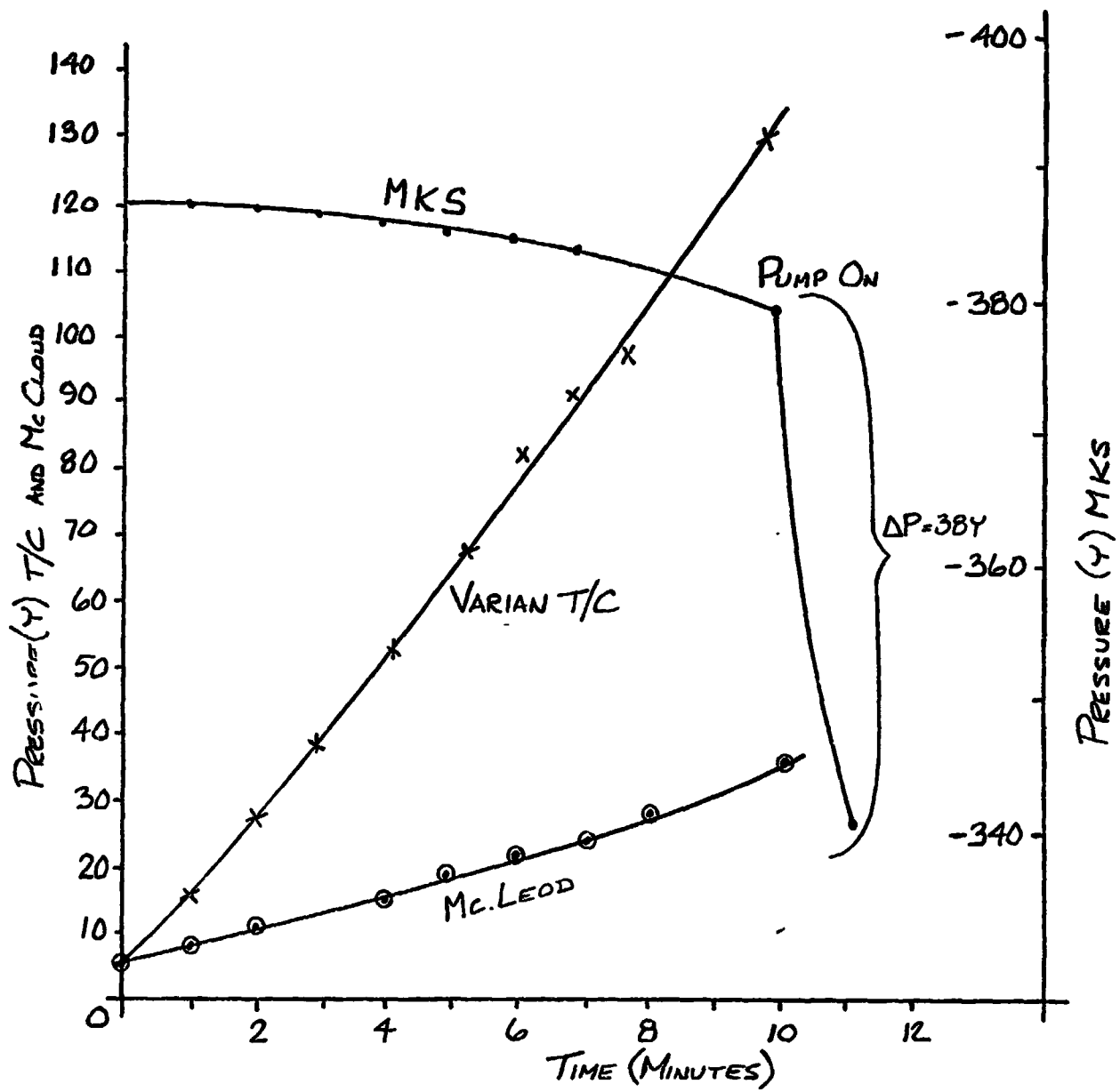
T.E. SET AT 2,500

Fig. 7

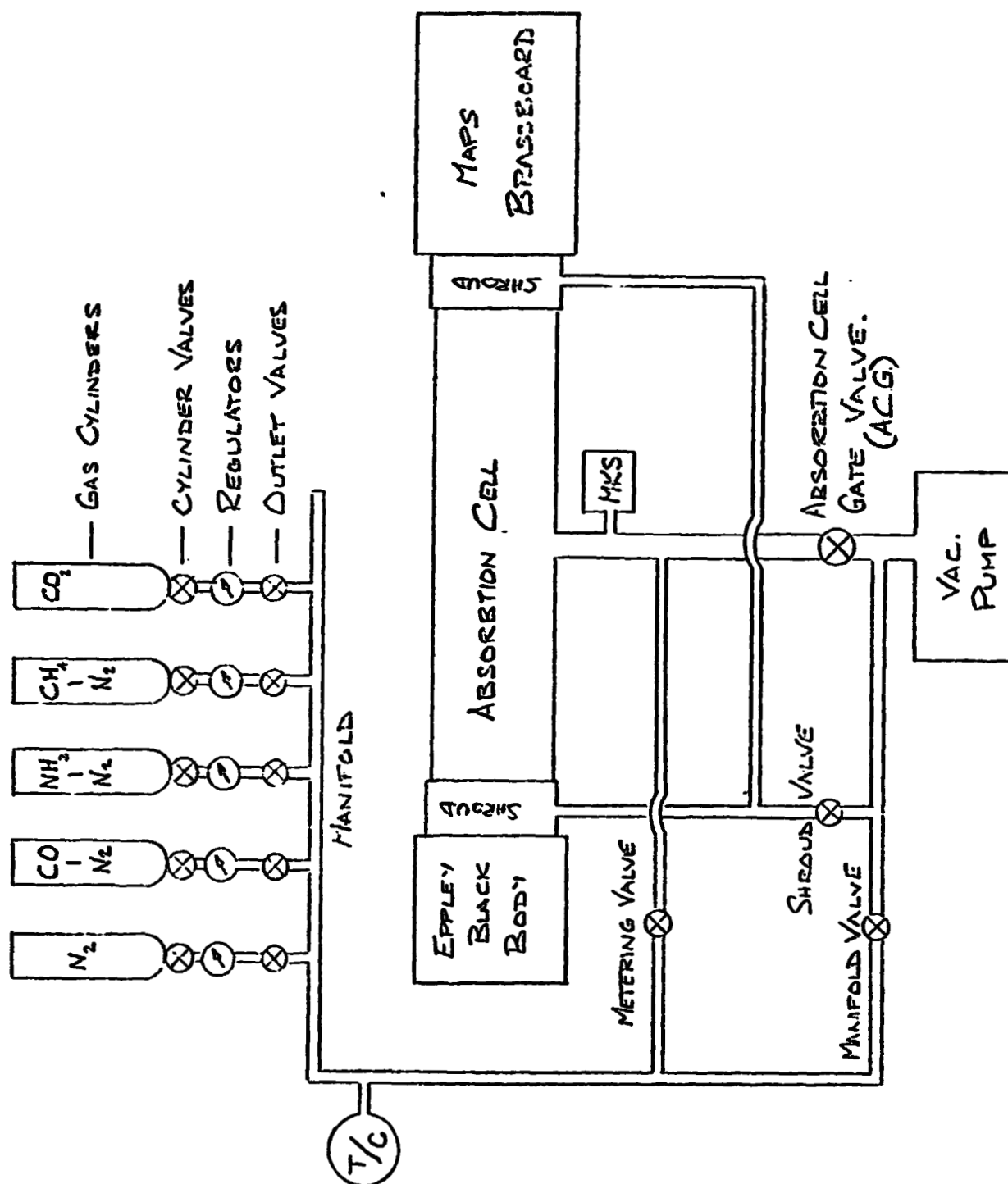


GSU CELL
PUMP DOWN TESTS (MKS GUAGE)
JULY 25th 1975

FIG. 8



GAS CELL LEAK TEST



G.S.U. SCHEMATIC

- ☐ Shipping, after shipment
to ☐ Cost Accounting
☐ Shipping File
☐ Open Shipping Order File
☐ Cost Accounting

SHIPPING ORDER/REPORT NO: 8815-USA

Cross References
Job No: 196-11
Job Order No: _____
Receiving Report No: _____

Ship to TR.W. Systems Group.
TR.W. Inc.

3001 Aviation Rd.

Manhattan Beach.

Cal. M.S. 13.

via air C SCHIFF Traffic

Bill to Comair 213-535-0796

for ☒ Sale, ☐ rental, ☐ loan,
☐ testing, ☐ return after repair
☐ other (explain) _____

from ☐ Stock-Material
☐ Stock-Finished Goods
☒ Contract
☐ Our Equipment
☐ Other (explain) _____

ship ☐ collect or ☒ prepaid
shipping insurance value \$ _____
when _____
off premises insurance yes ☐ no ☐

Quantity	DESCRIPTION	Serial No.	Unit Price
1	Auxiliary equipment ground		
1	Support Unit		50.00 - 02
1	C.S.V. Unit		50.00 - 02
	Freight Chg. 276.00		
	Insurance Cost 150.00		
	Contract # NAS-I-13695-		
	Sub. Cont. A39260 R DRS (75-1985-RA-076)		
	Custom Clearance by		
	Packer Int. Brokers		
	11217 South La Cienega Blvd.		
	L.A. Cal.		

Please check when completed:

- Labels (2) ☒
Packing Slips (4) ☒
Pro forma invoices (4) ☒
Customs form - E13 (5) ☒
- Australia (3) ☒
Waybill 0690 0003 ☒

Shipping Report

Date shipped Sept 19/73 ☐ collect or ☒ prepaid

via Comair

Entered in Off Premises Insurance Register ☐ yes ☒ no

Signed [Signature]

APPENDIX G

MAPS ELECTRONICS BREADBOARD TEST PROCEDURE

TEST DATA COPY

Revision A
August 11, 1975

MAPS ELECTRONICS
BREADBOARD TEST PROCEDURE

1.0 SCOPE

This procedure covers the final performance testing of the MAPS Electronics breadboard exclusive of the circuitry contained in the opto-mechanical head assembly.

2.0 TEST CONDITIONS

2.1 Test Article

The MAPS electronics breadboard consists of a chassis assembly containing 4 breadboard circuit assemblies whose sketch schematic identification is as follows:

- Bd. #1 - SK-MAPS-BB-101, Temperature Control and Motor Drive
- Bd. #2 - SK-MAPS-BB-102, Signal Processing - A
- Bd. #3 - SK-MAPS-BB-103, Signal Processing - B
- Bd. #4 - SK-MAPS-BB-104, Temperature Sense and Bias Regulators

Breadboard input/output connections are delineated in sketch # SK-MAPS-BB-107.

2.2 Test Equipment

Testing of the breadboard will be performed using the special power supply panel to provide the various secondary voltages. Inputs simulating signals from the opto-mechanical sensing head will be provided from a special head simulating kludge box.

Simulation of various thermistor inputs will be provided by decade resistance boxes. The motor, heater, and T. E. Cooler loads will be represented by a set of load resistors.

In addition to the above mentioned special items, the following additional test equipment is needed:

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2.2 Test Equipment - continued

- Function Generator, Wavetek
- Oscilloscope, Tektronix
- W Type, Plug-in for Tektronix Scope
- DVM, DC and rms AC
- Counter, frequency
- Strip Chart Recorder, Sanborn
- Data Translator Box, TRW Special to interface DVM to an HP9100 Calculator
- HP9100 Calculator
- VOM

2.2.1 Test Equipment Description

2.2.1.1 Sensing Head Simulator

This unit provides the S and R timing inputs as well as the 3 simulated radiance input signals denoted $(S_1 + R_1)$, $(S_2 + R_2)$ and $(S_3 + R_3)$. Potentiometers on the simulator allow the adjustment of the balance signal level (R), the common scene signal level (S) and the addition of a small scene signal component to the $(S_1 + R_1)$ and $(S_3 + R_3)$ signals (simulating the ΔV and $\Delta V'$ signals).

In addition, the relative amplitudes of the $(S_1 + R_1)$ or $(S_3 + R_3)$ signals may be adjusted without changing the ratio of scene signal to balance signal. (This simulates individual channel gain variations.)

2.2.1.2 Load Simulator

The chopper motor, the BB heater, and the 3 T. E. Coolers are simulated by a set of load resistors as follows:

- 2-Motor Coils - 1000 ohms each (represents 60V case only)
- 1-BB Heater - 82.5 ohms
- 3-TE Coolers - 21.5 ohms each

2.2.1.3 Data Reduction Unit

This unit accepts data from the Digital Voltmeter and formats it for readout to a HP9100 calculator. The calculator is then programmed to provide the mean and standard deviation of a selected number of DVM readings.

3.0 PROCEDURE

3.1 Procedure Performance

The step-by-step procedure for the functional testing is given below. The test sequence given is not mandatory. Test results should be recorded in the spaces provided in the body of the procedure.

3.2 Test Setup and Preliminary Checks

Interconnect the MAPS breadboard and the power switching unit. Connect the head simulator to the breadboard via a breakout box to head connector J3. Connect the dummy loads to head connector J2.

Switch on the electronics and measure and record the following input and bias voltages:

(a) Inputs

- +15V IN @ pin 1 of J1 = +14.99V
- -15V IN @ pin 2 of J1 = -15.05V
- + 5V IN @ pin 3 of J1 = +4.98V

(b) Regulated ±12V Outputs

- +12V-1 @ pin 7 of J3 = +12.01V
- +12V-2 @ pin 8 of J3 = +12.01V
- +12V-3 @ pin 9 of J3 = +12.01V
- -12V-1 @ pin 10 of J3 = -12.01V
- -12V-2 @ pin 11 of J3 = -12.01V
- -12V-3 @ pin 12 of J3 = -12.01V

(c) Internal ±10V Bias Voltages

- +10V @ pin 6 of AR7, Board 3 = +9.992V
- -10V @ pin 6 of AR8, Board 3 = -9.992V

(d) Regulated +100V Output

Switch on the +130 volt input and measure the following voltages:

- +130V input @ pin 7 of J1 = +120.5V
- 100V-1 @ pin 38 of J3 = 100.13V
- 100V-2 @ pin 39 of J3 = 100.18V
- 100V-3 @ pin 40 of J3 = 100.13V

3.3 Motor Driver Tests

The purpose of these tests is to check out the 2 phase synchronous motor drive electronics.

The circuit can operate at 3 selectable frequencies using an internal clock or can use an external clock. The motor drive voltage also has three selectable values as determined by a switch on the unit power panel. The test sequence is as follows:

- (a) Set the breadboard clock frequency switch in the low position and the clock select switch in the internal position.
- (b) Put the motor voltage switch on the power panel into the 20 volt position.
- (c) Turn on the motor voltage and check the ϕA and ϕB motor drive signal at pins 9 and 11 of J2.
- (d) Verify that square wave outputs are present with an oscilloscope. Measure and record the peak to peak amplitude and verify that a 90° phase relationship exists. Also measure the drive signal frequency. Record the results below:

- PP voltage, ϕA = 32VPP
- PP voltage, ϕB = 32VPP
- 90° phasing = ✓
- Drive frequency = 30.96 Hz

- (e) Switch the frequency select switch to the mid and high positions and record the drive frequency.

- Mid position 113 Hz.
- Hi position 225 Hz.

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3.3 Motor Driver Tests - continued

- (f) Return the frequency select switch to the low position and switch the motor voltage switch to the 40 volt position. Measure the peak to peak drive outputs.

- PP voltage, ϕA = 72VPP
- PP voltage, ϕB = 72VPP

- (g) Put the motor voltage switch in the 60 volt position and repeat step (f).

- PP voltage, ϕA = 120VPP
- PP voltage, ϕB = 120VPP

- (h) Put the clock select switch in the external position. Verify that the ϕA and ϕB outputs go to zero.

Outputs zero, ✓ Check to verify

- (i) Connect a square wave function generator to the external clock input and adjust for a 100 Hz square wave output of 5 volts peak to peak about zero. Check the ϕA and ϕB outputs and verify that the output drive is at one-fourth of the input frequency.

✓ Check to verify

3.4 Thermoelectric Cooler Drive Tests

The purpose of these tests is to verify the correct operation of the 3 emitter followers which supply constant voltage drive to the thermoelectric coolers.

The test sequence is as follows:

- (a) Turn on the T.E. cooler voltage at the power panel and measure the dc voltage into the unit on pin 16 of J1.

T.E. Cooler Input Voltage = 6.905 volts.

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August 11, 1975

3.1 Thermoelectric Cooler Drive Tests - continued

- (b) Connect the DVM across the load resistor connected to pins 1 and 2 of J2 to monitor the drive voltage. Adjust potentiometer R51 on Board #2 to vary the output voltage to the load. Measure and record the minimum and maximum output capability and set the pot for 3.5 volts out. Record results below.

T.E. Cooler #1

- Minimum voltage = 1.728v, (\leq 2V)
- Maximum voltage = 5.76v, ($>$ 5.5V)
- Set point voltage = 3.5v, (3.5V)

- (c) Repeat step (b) for T.E. Cooler #2 adjusting R52.

T.E. Cooler #2

- Minimum voltage = 1.65v, (\leq 2V)
- Maximum voltage = 5.67v, ($>$ 5.5V)
- Set point voltage = 3.5v, (3.5V)

- (d) Repeat step (b) for T.E. Cooler #3 adjusting R53.

T.E. Cooler #3

- Minimum voltage = 1.68v, (\leq 2V)
- Maximum voltage = 5.75v, ($>$ 5.5V)
- Set point voltage = 3.5v, (3.5V)

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Revision /
August 11, 1975

3.5 Temperature Sensing Circuit Tests

These tests check the operation of the six temperature readout circuits on Board #4 (schematic SK-MAPS BB-104). A variable resistance box is to be used to simulate the variable resistance of the sensing thermistor. Measure and record the bridge bias voltage at the emitter of Q4 on Board #4.

6.408 volts (requirement = $6.4V \pm 0.02 V$)

3.5.1 Blackbody #1 Temperature Sense Circuit

Connect a variable resistance box to pins 22 and 23 of J3. For each of the resistance box settings given below, measure and record the voltage at the BB#1 temperature output (pin 5 of J4).

<u>Simulated Temperature</u>	<u>BB#1 Thermistor Resistance (Ohms)</u>	<u>BB#1 Temperature Voltage (Volts)</u>
0°C	7355	<u>-5.967</u>
5°C	5719	<u>-4.724</u>
7°C	5183	<u>-4.201</u>
10°C	4482	<u>-3.354</u>
15°C	3539	<u>-2.010</u>
17°C	3226	<u>-1.448</u>
20°C	2814	<u>-0.607</u>
22°C	2572	<u>-0.048</u>
25°C	2252	<u>+1.775</u>
27°C	2064	<u>+1.321</u>
30°C	1815	<u>+2.112</u>
32°C	1667	<u>+2.627</u>
35°C	1471	<u>+3.371</u>
37°C	1355	<u>+3.847</u>
40°C	1200	<u>+4.511</u>
45°C	984	<u>+5.588</u>

3.5.2 Blackbody #2 Temperature Sense Circuit

Repeat the test of paragraph 3.5.1 for blackbody #2. Connect the resistance box to pins 24 and 25 of J3. Read the output at pin 6 of J4. Record results below:

<u>Simulated Temperature</u>	<u>BB#2 Thermistor Resistance (Ohms)</u>	<u>BB#2 Temperature Voltage (Volts)</u>
0°C	7355	<u>-5.970</u>
5°C	5719	<u>-4.727</u>
7°C	5183	<u>-4.204</u>
10°C	4482	<u>-3.528</u>
15°C	3539	<u>-2.013</u>
17°C	3226	<u>-1.452</u>
20°C	2814	<u>-0.610</u>
22°C	2572	<u>-0.051</u>
25°C	2252	<u>+1.276</u>
27°C	2064	<u>+1.317</u>
30°C	1815	<u>+2.103</u>
32°C	1667	<u>+2.624</u>
35°C	1471	<u>+3.367</u>
37°C	1355	<u>+3.944</u>
40°C	1200	<u>+4.527</u>
45°C	984	<u>+5.581</u>

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August 11, 1975

3.5.3 Blackbody #3 Temperature Sense Circuit

Repeat the test of paragraph 3.5.1 for blackbody #3. Connect the variable resistance box to pins 26 and 27 of J3. Monitor the voltage at pin 7 of J4. Record the voltage for the following resistance values.

<u>Simulated Temperature</u>	<u>BB#3 Thermistor Resistance (Ohms)</u>	<u>BB#3 Temperature Voltage (Volts)</u>
61°C	2669	<u>-7.187</u>
63°C	2497	<u>-6.234</u>
65°C	2339	<u>-5.283</u>
67°C	2191	<u>-4.307</u>
69°C	2055	<u>-3.360</u>
71°C	1928	<u>-2.378</u>
73°C	1810	<u>-1.438</u>
75°C	1700	<u>-0.471</u>
77°C	1598	<u>+0.467</u>
79°C	1503	<u>+1.407</u>
81°C	1414	<u>+2.344</u>
83°C	1332	<u>+3.258</u>
85°C	1255	<u>+4.166</u>
87°C	1183	<u>+5.062</u>
89°C	1116	<u>+5.939</u>
91°C	1053	<u>+6.806</u>

3.5.4 Detector Temperature Sense Circuit Tests

Each of the 3 detector thermistor bridge circuits must be matched to the characteristics of the detector thermistor by the selection of a fixed resistance to be placed in parallel with the thermistor.

Values selected for these tests were picked to match detector vendor thermistor data on the 3 detectors delivered for brassboard use.

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3.5.4 Detector Temperature Sense Circuit Tests - continued

(a) Detector #1 Test

Install a 124K $\pm 1\%$ shunt as K68 on Board #4. Connect the variable resistance box to pins 16 and 17 of J3. Read the output on pin 8 of J4.

<u>Simulated Temperature</u>	<u>Thermistor Resistance</u>	<u>Voltage</u>
-65°C	145K	<u>+1.96V</u>
-67°C	175K	<u>+1.429V</u>
-70°C	230K	<u>+0.757V</u>
-73°C	310K	<u>+0.154V</u>
-75°C	390K	<u>-0.224V</u>
-80°C	710K	<u>-0.934V</u>

(b) Detector #2 Test

Install a 210K shunt as R69 on Board #4. Connect the variable resistance box to pins 18 and 19 of J3. Read the output on pin 9 of J4.

<u>Simulated Temperature</u>	<u>Thermistor Resistance</u>	<u>Voltage</u>
-60°C	75K	<u>+3.215V</u>
-65°C	92K	<u>+2.033V</u>
-70°C	128K	<u>+0.867V</u>
-75°C	174K	<u>-0.262V</u>
-80°C	250K	<u>-1.365V</u>
-85°C	380K	<u>-2.344V</u>
-90°C	600K	<u>-3.109V</u>

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3.5.4 Detector Temperature Sense Circuit Tests - continued

(c) Detector #3 Test

Install a 261K $\pm 1\%$ shunt as R70 on Board #4. Connect the variable resistance box to pins 20 and 21 of J3. Read the voltage at pin 10 of J4.

<u>Simulated Temperature</u>	<u>Thermistor Resistance</u>	<u>Voltage</u>
-60°C	62K	<u>+3.835</u>
-65°C	84K	<u>+2.364</u>
-70°C	112K	<u>0.955</u>
-75°C	150K	<u>-0.271</u>
-80°C	208K	<u>-1.447</u>
-85°C	300K	<u>-2.517</u>
-90°C	420K	<u>-3.282</u>

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3.6 Blackbody Temperature Control Circuit Tests

The purpose of these tests is to check the operation of the on-off temperature control circuitry of Board #1.

- (a) Adjust R39 on Board #1 so that the center arm voltage (junction of the pot and R37) is zero ± 10 millivolts.
- (b) Connect a decade resistance box to simulate BB #3 thermistor (pins 16 and 27 of J3).
- (c) Set dead zone potentiometer R66 to the center of its adjustment range.
- (d) Connect a DVM across the Heater load at pin 7 and 8 of J2.
- (e) Set the decade resistance box to 2055Ω , turn on the Heater voltage supply and measure the voltage across the heater load.

Load voltage 27.7, (28V)

- (f) Set the decade resistance box to 1503 ohms and measure the load voltage.

Load voltage 0, (0 V)

- (g) Slowly increase value of resistance until load voltage goes on. Note resistance. Slowly decrease the resistance until the load voltage goes off. Repeat the above procedure several times to determine the equivalent on-off switching points and hysteresis.

Switch on Resistance = 1643 ohms ($\approx 76^{\circ}\text{C}$)
Switch off Resistance = 1587 ohms.

- (h) Turn the temperature set point potentiometer R39 fully clockwise and repeat step (g).

Switch on Resistance = 1424 ohms ($\approx 82^{\circ}\text{C}$)
Switch off Resistance = 1365 ohms.

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3.. Blackbody Temperature Control Circuit Tests - continued

- (i) Turn the set point control R39 fully ccw and repeat step (g).

Switch on Resistance = 1876 ohms ($\approx 72^{\circ}\text{C}$)
Switch off Resistance = 1812 ohms.

Return R39 to the center of its control range.

- (j) Adjust dead zone control R66 fully clockwise and repeat the test of step (g). Note R39 should be in the mid-range position per step (g).

Switch on Resistance = 1651 ohms
Switch off Resistance = 1649 ohms.

- (k) Adjust dead zone control R66 fully counterclockwise and repeat the test of step (g).

Switch on Resistance = 1651 ohms
Switch off Resistance = 1576 ohms.

- (l) Return R66 to its mid-range position and R39 to the center set point position.

3.7 Signal Processing Circuit Tests

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The sequence of signal processing tests are to be performed at both the low and the high chopping frequencies. The pick off phase adjustments for the S and R demodulators must be adjusted separately for each operating frequency.

In addition, the ΔV and $\Delta V'$ difference amplifier trim resistors (R29, R33, R37, and R38) must be separately selected for minimum V signal feedthrough at each chopping frequency.

3.7.1 Low Chopping Frequency Tests (NH₃ Mode)

For the tests which follow, the head simulator is set in the low frequency mode (25 Hz scene, 50 Hz balance) and the bandwidth limit switch is to be placed in the low position.

The demodulator phasing should be adjusted and the ΔV and $\Delta V'$ difference amplifier trimming should be made before proceeding. Record the trim resistor values below.

For ΔV , R29 = 0, R33 = 0

For $\Delta V'$, R37 = 432, R38 = 0

3.7.1.1 V Signal Gain and Linearity

The purpose of this test is to check the gain and linearity of the V output as the common scene input is varied. For this test the output is measured with a DVM at pin 2 of J4.

A composite (S + R) test signal from the head simulator shall be fed into the $S_2 + R_2$ input (J3, pin 3). The R component shall be set to zero and the peak to peak S value shall be accurately set to the values listed below through the use of an oscilloscope with a W type plug-in.

Also measure and record the rms ac input with a DVM. (DANA 4530 or equivalent).

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<u>S Input</u> <u>PP</u>	<u>S Input</u> <u>AC RMS</u>	<u>V Signal</u> <u>Output</u>
0 Vpp	<u>0</u>	<u>- .3mV</u>
+2 Vpp	<u>1.07V</u>	<u>1.46V</u>
+4 Vpp	<u>2.14V</u>	<u>3.94V</u>
+6 Vpp	<u>3.24V</u>	<u>5.94V</u>
+8 Vpp	<u>4.31V</u>	<u>7.91V</u>
+10 Vpp	<u>5.37V</u>	<u>9.87V</u>

The expected gain is 1 volt dc per volt pp ac with a perfect square wave input.

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3.7.1.2 R Signal Gain and Linearity

The purpose of this test is to check the gain and linearity of the R output as the balance signal level is varied. The input connections are the same as paragraph 3.7.1.2. The scene component shall be set to zero and the R component shall be varied using a W type plug-in to set the pp level. The R output shall be measured at pin 1 of J4.

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<u>R Input PP</u>	<u>R Input AC RMS</u>	<u>R Signal Output</u>
0 Vpp	<u>0</u>	<u>+0.04V</u>
0.5 Vpp	<u>.267V</u>	<u>1.07V</u>
1.0 Vpp	<u>.53V</u>	<u>2.09V</u>
1.5 Vpp	<u>.796</u>	<u>3.12V</u>
2.0 Vpp	<u>1.06V</u>	<u>4.16V</u>

The expected gain is 2.5 Vdc per volt pp ac with a perfect square wave input.

3.7.1.3 ΔV , $\Delta V'$ Signal Gain and Linearity

The purpose of these tests is to check the gain and linearity of the ΔV and $\Delta V'$ output as the S_1 and S_3 signals are varied relative to the S_2 signal level.

For this test, all 3 simulated radiance inputs are required as follows:

- ($S_1 + R_1$) to J3, pin 1
- ($S_2 + R_2$) to J3, pin 3
- ($S_3 + R_3$) to J3, pin 5

Set the common scene level and the ΔV level pots on the simulator to zero. Adjust the balance level pot until the R output is 2.50 volts ± 0.01 volts.

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The S component of the $S_1 + R_1$ and $S_3 + R_3$ inputs is then varied with the ΔV level control. The ΔV component of the inputs should be very accurately set up using a Tektronix oscilloscope with a W type plug-in. Record the data as listed below:

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(a) ΔV Test

S Component of $S_1 + R_1$	AC RMS $S_1 + R_1$ Voltage	ΔV Output
0 Vpp	<u>.6344V</u>	<u>+ 7mV</u>
0.05 Vpp	<u>.6345V</u>	<u>1.07V</u>
0.1 Vpp	<u>.6346</u>	<u>2.24V</u>

0.20 Vpp	<u>.6352V</u>	<u>4.40V</u>
0.40 Vpp	<u>.6368V</u>	<u>9.06V</u>

The expected gain is 22.5 volts dc/volt pp ac with a square wave input.

(b) $\Delta V'$ Test

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S Component of $S_3 + R_3$	AC RMS $S_3 + R_3$ Voltage	$\Delta V'$ Output
0 Vpp	<u>.6354V</u>	<u>+ 9mV</u>
0.05 Vpp	<u>.6356V</u>	<u>1.08V</u>
0.1 Vpp	<u>.6356V</u>	<u>2.23V</u>
0.15 Vpp	<u>.6357V</u>	<u>3.40V</u>
0.20 Vpp	<u>.6358V</u>	<u>4.54V</u>
0.25 Vpp	<u>.6360V</u>	<u>5.67V</u>
0.30 Vpp	<u>.6364V</u> ✓	<u>6.76V</u>
0.40 Vpp	<u>.6374V</u>	<u>9.16V</u>

The expected gain is 22.5 volts dc/volt pp ac with a square wave input.

3.7.1.4 AGC Balance Loop Time Constant Check

The purpose of these tests is to check the ΔV and $\Delta V'$ automatic gain balance loop time constants.

For these tests all 3 simulated radiance inputs are needed as per paragraph 3.7.1.3.

3.7.1.4.1 ΔV Channel Balance Time Constant Check

- (a) Adjust the scene and balance level controls for an R output of 2.5 volts and a V output of 5.0 volts. The ΔV control should be at zero.
- (b) Adjust the simulator gain dials to make the R component of the $(S_1 + R_1)$ signal equal to 1V pp and the R component of the $(S_3 + R_3)$ signal equal to 1.5 volts pp.
- (c) Feed the $(S_1 + R_1)$ and $(S_3 + R_3)$ simulated radiance signals to a selector switch and feed the switch output to the $(S_1 + R_1)$ input of the unit (pin 1 of J3).
- (d) Set up the Sanborn strip chart recorder to monitor the ΔV AGC integrator voltage. (Pin 6 of AR13 on Board #2)
- (e) By switching the $(S_1 + R_1)$ input selector switch back and forth between the $(S_1 + R_1)$ and $(S_3 + R_3)$ signal, an exponential change in the integrator output voltage will be observed.
- (f) Use the Sanborn Recorder to record the voltage and measure the time for the voltage to change 63% of the total change value when the selector switch is changed from the $S_3 + R_3$ to the $S_1 + R_1$ position. Repeat going from $S_1 + R_1$ to $S_3 + R_3$ switch position.

3.7.1.4.1 ΔV Channel Balance Time Constant Check - continued

(g) Record the measured time constant and other data as outlined below:

- R output = 2.500 Volts
- V output = 5.000 Volts
- ($S_1 + R_1$) Signal- Total pp value = 5.25 Vpp
 - R component = 1.0 Vpp
 - S component = 4.30 Vpp
- ($S_3 + R_3$) Signal- Total pp value = 7.7 Vpp
 - R component = 1.5 Vpp
 - S component = 6.3 Vpp
- Time Constant going from
 ($S_3 + R_3$) to ($S_1 + R_1$) = ~~11.5~~ 19.2 Seconds
- Time Constant going from
 ($S_1 + R_1$) to ($S_3 + R_3$) = ~~19.2~~ 11.5 Seconds

3.7.1.4.2 $\Delta V'$ Channel Balance Time Constant Check

Repeat paragraph 3.7.1.4.1 for the $\Delta V'$ Channel. Feed the switch selected signal into the $S_3 + R_3$ input (pin 5 of J3). Connect the Sanborn recorder to pin 6 of AR15 on Board #2.

Record the following data:

- R output = 2.5 Volts
- V output = 5.001 Volts
- $S_1 + R_1$ Signal = 5.25 Vpp
 - S component = 4.3 Vpp
 - R component = 1.0 Vpp
- $S_3 + R_3$ Signal
 - Total = 7.7 Vpp
 - S component = 6.3 Vpp
 - R component = 1.5 Vpp
- Time Constant going from
 ($S_3 + R_3$) to ($S_1 + R_1$) = ~~11.5~~ 19.2 Seconds
- Time Constant going from
 ($S_1 + R_1$) to ($S_3 + R_3$) = ~~19.2~~ 12.4 Seconds

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3.7.1.5 Effects of Common V Signal on the ΔV , $\Delta V'$ and R Outputs.

The purpose of these tests is to determine the effects of the large common scene signal upon the ΔV and $\Delta V'$ outputs and upon the R output.

Set up the input simulator to supply all 3 inputs. Set the ($S_1 + R_1$) and ($S_3 + R_3$) gain controls to the 500 dial setting.

Set the ΔV level to zero and the balance level for a 2.5V R signal.

For various ΔV output levels, vary the scene level to obtain the V signals shown below and record the values of ΔV and $\Delta V'$ output. When measuring the ΔV and $\Delta V'$ outputs, use the HP9100A calculator to obtain 100 sample mean and standard deviation values. Wait 5 minutes after each V signal level change to allow the AGC loops to stabilize.

(a) Run #1 ΔV Set to Zero

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev	Mean	Std Dev
0V	<u>2.418V</u>	<u>+7mV</u>	<u>—</u>	<u>+3mV</u>	<u>—</u>
2V	<u>2.500V</u>	<u>+3.8</u>	<u>$\pm 1.5mV$</u>	<u>+0.2mV</u>	<u>$\pm 1.2mV$</u>
4V	<u>2.500</u>	<u>+5.1mV</u>	<u>$\pm 4mV$</u>	<u>+3.6mV</u>	<u>$\pm 2.6mV$</u>
6V	<u>2.504</u>	<u>+7.9mV</u>	<u>$\pm 2.9mV$</u>	<u>+13.1mV</u>	<u>$\pm 2.5mV$</u>
8V	<u>2.484</u>	<u>+16.9mV</u>	<u>$\pm 9.7mV$</u>	<u>+25.3mV</u>	<u>$\pm 4.4mV$</u>

(b) Run #2 ΔV Set to +2V when V = 0

8/13/75

V Output (Volts dc)	R Output (Volts dc)	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev	Mean	Std Dev
0V	<u>2.418V</u>	<u>2.002V</u>	<u>—</u>	<u>2.031V</u>	<u>—</u>
2V	<u>2.500V</u>	<u>1.998V</u>	<u>$\pm 2.9mV$</u>	<u>2.028V</u>	<u>$\pm 1.5V$</u>
4V	<u>2.502V</u>	<u>1.995V</u>	<u>$\pm 4.3mV$</u>	<u>2.029V</u>	<u>$\pm 2.5V$</u>
6V	<u>2.504V</u>	<u>2.001V</u>	<u>$\pm 7.4mV$</u>	<u>2.034V</u>	<u>$\pm 3.9V$</u>
8V	<u>2.484V</u>	<u>2.006V</u>	<u>$\pm 12.8mV$</u>	<u>2.053V</u>	<u>$\pm 5.7mV$</u>

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3.7.1.5 Effects of Common V Signal on the ΔV , $\Delta V'$ and R Outputs - continued

(c) Run #3 ΔV Set to 4V when V = 0

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev	Mean	Std Dev
0V	<u>2.484V</u>	<u>4.000V</u>	—	<u>4.062V</u>	—
2V	<u>2.500V</u>	<u>3.994V</u>	$\pm 2.5mV$	<u>4.058V</u>	$\pm 2.9mV$
4V	<u>2.503V</u>	<u>3.993V</u>	$\pm 6.7mV$	<u>4.058V</u>	$\pm 3.3mV$
6V	<u>2.505V</u>	<u>3.995V</u>	$\pm 8.3mV$	<u>4.064V</u>	$\pm 3.8mV$
8V	<u>2.479V</u>	<u>4.003V</u>	$\pm 7.2mV$	<u>4.081V</u>	$\pm 7.0mV$

(d) Run #4 ΔV Set to 6V when V = 0

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev	Mean	Std Dev
0V	<u>2.498V</u>	<u>6.000V</u>	—	<u>6.094V</u>	—
2V	<u>2.500V</u>	<u>5.996V</u>	$\pm 2.4mV$	<u>6.094V</u>	$\pm 2.3mV$
4V	<u>2.503V</u>	<u>5.997V</u>	$\pm 5.5mV$	<u>6.095V</u>	$\pm 4.9mV$
6V	<u>2.504V</u>	<u>5.995V</u>	$\pm 5.8mV$	<u>6.101V</u>	$\pm 6.9mV$
8V	<u>2.476V</u>	<u>6.005V</u>	$\pm 6.9mV$	<u>6.117V</u>	$\pm 6.1mV$

3.7.1.6 Effects of Channel Gain Variation Upon the ΔV and $\Delta V'$ Outputs

The purpose of this test is to measure the effect of changes in the optical path, detectors and preamplifiers, which cause a common reduction in both the S and R component of the input to the signal processing circuits.

This effect is simulated by the $(S_1 + R_1)$ and $(S_3 + R_3)$ gain controls on the head simulator. With the gain pots set to the mid-range position (dial reading of 500), adjust the scene level for a 4 volt V output. Adjust the balance level for a 2.5 volt R output. Adjust the ΔV control for a 2 volt ΔV output.

With an ac reading DVM, measure and record the $(S_1 + R_1)$, $(S_2 + R_2)$, and $(S_3 + R_3)$ input voltages. Record in the table below. Then adjust the gain pot settings to obtain ± 10 percent and $\pm 25\%$ changes in the $(S_1 + R_1)$ and $(S_3 + R_3)$ ac voltage readings. After making each gain setting, allow at least 15 minutes for the AGC loop to react and reach its final value before recording data.

The ΔV and $\Delta V'$ readings should be in the mean of 100 samples using the HP9100 calculator.

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Gain Balance	$S_1 + R_1$ RMS	$S_2 + R_2$ RMS	$S_3 + R_3$ RMS	V Volts, dc	ΔV Volts, dc	$\Delta V'$ Volts, dc	R Volts, dc
Equal	<u>2.223V</u>	<u>2.175V</u>	<u>2.223V</u>	<u>4.003V</u>	<u>2.006V</u>	<u>2.039V</u>	<u>2.500V</u>
+10%	<u>2.445V</u>	<u>2.175V</u>	<u>2.445V</u>	<u>4.003V</u>	<u>2.006V</u>	<u>2.039V</u>	<u>2.501V</u>
+25%	<u>2.776V</u>	<u>2.175V</u>	<u>2.776V</u>	<u>4.002V</u>	<u>2.003V</u>	<u>2.039V</u>	<u>2.501V</u>
-10%	<u>2.000V</u>	<u>2.175V</u>	<u>2.000V</u>	<u>4.002V</u>	<u>2.003V</u>	<u>2.039V</u>	<u>2.501V</u>
-25%	<u>1.667V</u>	<u>2.175V</u>	<u>1.667V</u>	<u>4.002V</u>	<u>2.002V</u>	<u>2.039V</u>	<u>2.501V</u>
Equal	<u>2.223V</u>	<u>2.175V</u>	<u>2.223V</u>	<u>4.002V</u>	<u>2.004V</u>	<u>2.039V</u>	<u>2.501V</u>

3.7.2 High Chopping Frequency Tests (CO Mode)

These tests are very nearly a repeat of the tests of paragraph 3.7.1 at the 172/340 Hertz chopping rate.

Put the head simulator in the high frequency mode and put the bandwidth limit switch in the high position.

Demodulator phasing adjustments and the ΔV and $\Delta V'$ difference amplifier trimming should be made before proceeding. Record the trim resistor values below:

For ΔV , R29 = 0, R33 = 20

For $\Delta V'$, R37 = 51, R38 = 0

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3.7.2.1 V Signal Gain and Linearity

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Repeat paragraph 3.7.1.1 at the high chopping frequency. Record the data below:

<u>S Input PP</u>	<u>S Input AC RMS</u>	<u>V Signal Output</u>
0 Vpp	<u>0</u>	<u>+2mV</u>
+2 Vpp	<u>1.084V</u>	<u>1.97V</u>
+4 Vpp	<u>2.17V</u>	<u>3.95V</u>
+6 Vpp	<u>3.27V</u>	<u>5.94V</u>
+8 Vpp	<u>4.34V</u>	<u>7.89V</u>
+10 Vpp	<u>5.38V</u>	<u>9.79V</u>

The expected gain is 1.0 volts dc per volt pp ac for a square wave input.

3.7.2.2 R Signal Gain and Linearity

Repeat paragraph 3.7.1.2 at the high chopping frequency. Record the data below:

<u>R Input PP</u>	<u>R Input AC RMS</u>	<u>R Signal Output</u>
0 Vpp	<u>0</u>	<u>1.04V</u>
0.5 Vpp	<u>.263V</u>	<u>1.07V</u>
1.0 Vpp	<u>0.528V</u>	<u>2.10V</u>
1.5 Vpp	<u>0.796V</u>	<u>3.15V</u>
2.0 Vpp	<u>1.06V</u>	<u>4.16V</u>
2.5 Vpp	<u>1.32V</u>	<u>5.18V</u>
3.0 Vpp	<u>1.58V</u>	<u>6.19V</u>

The expected gain is 2.5V dc per volt pp ac with a square wave input.

3.7.2.3 ΔV and $\Delta V'$ Signal Gain and Linearity

Repeat paragraph 3.7.1.3 at the high chopping frequency. Record the data as listed below:

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(a) ΔV Test

S Component of $S_1 + R_1$	AC RMS $S_1 + R_1$ Voltage	ΔV Output
0 Vpp	<u>.6315V</u>	<u>+4.01V</u>
0.05 Vpp	<u>.6317V</u>	<u>+1.09V</u>
0.1 Vpp	<u>.6319V</u>	<u>+2.18V</u>
0.15 Vpp	<u>.6321V</u>	<u>+3.36V</u>
		<u>+4.42V</u>

(b) $\Delta V'$ Test

S Component of $S_3 + R_2$	AC RMS $S_3 + R_3$ Voltage	ΔV Output
0 Vpp	<u>.6309V</u>	<u>+0.03V</u>
0.05 Vpp	<u>.6310V</u>	<u>+1.09V</u>
0.1 Vpp	<u>.6312V</u>	<u>+2.23V</u>
0.15 Vpp	<u>.6318V</u>	<u>+3.33V</u>
0.20 Vpp	<u>.6321V</u>	<u>+4.49V</u>
0.25 Vpp	<u>.6324V</u>	<u>+5.57V</u>
0.30 Vpp	<u>.6327V</u>	<u>+6.63V</u>
0.40 Vpp	<u>.6330V</u>	<u>+9.05V</u>

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3.7.2.4 AGC Balance Loop Time Constant Check

Repeat the first 3 runs of paragraph 3.7.1.4 at the high chopping frequency.

(a) (a) ΔV Channel-Test per paragraph 3.7.1.4.1 and record data below:

- R output = 2.533 Volts
- V output = 5.013 Volts
- $(S_1 + R_1)$ Signal- Total pp value = 5.25 Vpp
 - R component = 1.0 Vpp
 - S component = 4.25 Vpp
- $(S_3 + R_3)$ Signal- Total pp value = 7.7 Vpp
 - R component = 1.48 Vpp
 - S component = 6.3 Vpp
- Time Constant going from $(S_3 + R_3)$ to $(S_1 + R_1)$ = ~~20.5~~ Seconds
- Time Constant going from $(S_1 + R_1)$ to $(S_3 + R_3)$ = ~~8.2~~ Seconds

(b) $\Delta V'$ Channel - Test per paragraph 3.7.1.4.2 and record data below:

- R output = 2.533 Volts
- V output = 5.013 Volts
- $S_1 + R_1$ Signal = 5.25 Vpp
 - S component = 4.3 Vpp
 - R component = 1.0 Vpp
- $S_3 + R_3$ Signal
 - Total = 7.7 Vpp
 - S component = 6.3 Vpp
 - R component = 1.5 Vpp
- Time Constant going from $(S_3 + R_3)$ to $(S_1 + R_1)$ = ~~18.5~~ Seconds
- Time Constant going from $(S_1 + R_1)$ to $(S_3 + R_3)$ = ~~12.2~~ Seconds

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3.7.2.5 Effects of Common V Signal on the ΔV , $\Delta V'$, and R Outputs

Repeat the tests of paragraph 3.7.1.3 at the high chopping frequency. Record the test results below:

(a) Run #1 ΔV Set to Zero

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev	Mean	Std Dev
0V	<u>2.50V</u>	<u>4mV</u>	<u>0</u>	<u>-6mV</u>	<u>0</u>
2V	<u>2.514V</u>	<u>+10mV</u>	<u>0</u>	<u>-4mV</u>	<u>0</u>
4V	<u>2.526V</u>	<u>+18.4mV</u>	<u>±1.6mV</u>	<u>-1.2mV</u>	<u>±1.4mV</u>
6V	<u>2.524V</u>	<u>+30.2mV</u>	<u>±1.5mV</u>	<u>+6.7mV</u>	<u>±2.1mV</u>
8V	<u>2.538V</u>	<u>+45.3mV</u>	<u>±5.4mV</u>	<u>+19.5mV</u>	<u>±2.3mV</u>

(b) Run #2 ΔV Set to +2V when V = 0

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev	Mean	Std Dev
0V	<u>2.50V</u>	<u>2.002V</u>	<u>0</u>	<u>2.024V</u>	<u>0</u>
2V	<u>2.514V</u>	<u>1.998V</u>	<u>±1.9mV</u>	<u>2.016V</u>	<u>±0.8mV</u>
4V	<u>2.527V</u>	<u>1.998V</u>	<u>±1.4mV</u>	<u>2.009V</u>	<u>±3mV</u>
6V	<u>2.524V</u>	<u>2.001V</u>	<u>±3.4mV</u>	<u>2.007V</u>	<u>±3.4mV</u>
8V	<u>2.538V</u>	<u>2.005V</u>	<u>±13.1mV</u>	<u>2.010V</u>	<u>±7.1mV</u>

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3.7.2.5 Effects of Common V signal on the ΔV , $\Delta V'$, and R Outputs - continued

(c) Run #3 ΔV Set to 4V when V = 0

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V Output (Volts dc)	R Output (Volts dc)	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev	Mean	Std Dev
0V	<u>2.501V</u>	<u>3.997V</u>	—	<u>4.051V</u>	—
2V	<u>2.514V</u>	<u>3.990V</u>	<u>$\pm 2.2mV$</u>	<u>4.040V</u>	<u>$\pm 3.3mV$</u>
4V	<u>2.527V</u>	<u>3.985V</u>	<u>$\pm 2.7mV$</u>	<u>4.032V</u>	<u>$\pm 5.7mV$</u>
6V	<u>2.526V</u>	<u>3.970V</u>	<u>$\pm 8.3mV$</u>	<u>4.025V</u>	<u>$\pm 8.3mV$</u>
8V	<u>2.531V</u>	<u>3.978V</u>	<u>$\pm 4.2mV$</u>	<u>4.025V</u>	<u>$\pm 12.8mV$</u>

3.7.2.6 Effects of Channel Gain Variation Upon the ΔV and $\Delta V'$ Outputs

Repeat the tests of paragraph 3.7.1.6 at the high chopping frequency. Record the test results below:

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Gain Balance	$S_1 + R_1$ RMS	$S_2 + R_2$ RMS	$S_3 + R_3$ RMS	V Volts, dc	ΔV Volts, dc	$\Delta V'$ Volts, dc	R Volts, dc
Equal	<u>2.258V</u>	<u>2.206V</u>	<u>2.256V</u>	<u>4.000V</u>	<u>2.002V</u>	<u>2.013V</u>	<u>2.499V</u>
+10%	<u>2.484V</u>	<u>2.206V</u>	<u>2.484V</u>	<u>4.000V</u>	<u>2.001V</u>	<u>2.012V</u>	<u>2.500V</u>
+25%	<u>2.813V</u>	<u>2.206V</u>	<u>2.823V</u>	<u>4.001V</u>	<u>1.998V</u>	<u>2.006V</u>	<u>2.500V</u>
-10%	<u>2.032V</u>	<u>2.206V</u>	<u>2.032V</u>	<u>4.000V</u>	<u>2.003V</u>	<u>2.017V</u>	<u>2.500V</u>
-25%	<u>1.693V</u>	<u>2.206V</u>	<u>1.693V</u>	<u>4.000V</u>	<u>2.002V</u>	<u>2.020V</u>	<u>2.500V</u>
Equal	<u>2.256V</u>	<u>2.206V</u>	<u>2.256V</u>	<u>3.999V</u>	<u>2.006V</u>	<u>2.016V</u>	<u>2.500V</u>

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3.8 Power Consumption Test

The purpose of this test is to determine the overall power consumed by the electronics under various operating conditions.

Using a VOM, measure and record the +15, -15, and +5 volt line current into the breadboard under the following test conditons.

(a) Electronics on Only, R = 2.5V, V = 4V, ΔV = 4V

+5V line = 44.5 ma 19ma when Heater Thermistor is Shorted
+15V line = 6.0 ma
-15V line = 3.7 ma

(b) Same as step (a) with the T.E. Cooler power,
Motor drive power, and the BB heater power on.

+5V line = 44.5 ma 14ma when Heater Thermistor is Shorted.
+15V line = 6.0 ma
-15V line = 3.7 ma

3.9 Phase Sensitivity Test

The purpose of this test is to evaluate the units performance with misaligned timing signals to the S and R synchronous demodulators.

The timing signals are developed by the chopper wheel pickoff circuits of signal processing Board B. Potentiometers R58 and R63 on this board allow adjustment of the S and R demodulator drive signals.

At each of the two chopping frequencies these pots are normally adjusted for maximum R and V outputs. For these tests they will be purposely misaligned to cause a $\pm 3\%$ phase error.

3.9.1 Low Frequency Phase Sensitivity Test

- (a) Set up the test situation of paragraph 3.7.1.3. Adjust the balance input for a 2.5 volt R signal, the Scene level for a 4.0V V signal and the ΔV level for a ΔV signal of 2.0 volts.
- (b) Check the timing of V signal and R signals relative to the demodulator switching signals and adjust R63 and R58 if necessary.
- (c) Readjust the inputs for the correct output levels if necessary. Record the readings in the table below as the baseline data:
- (d) Sync an oscilloscope on the R pickoff signal (pin 34 of J3) and monitor the R demodulator drive signal (pin 9 of Z2 on Board #2). Note the phase relationship of the R demodulator drive signal to the R pickoff signal and adjust R58 to delay the demodulator drive by 0.2 milliseconds (1%). Repeat the baseline readings, recording the data below.
- (e) Repeat step (d), only this time advance the demodulator drive by -0.2 milliseconds.
- (f) Return the R demodulator timing to the original R58 setting. Repeat the baseline data readings and record below.
- (g) Sync an oscilloscope on the S pickoff signal (pin 28 of J3) and monitor the V demodulator drive signal (pin 13 of Z1 of Board #3). Note the phase relationship of the V demodulator drive signal to the sync signal and adjust R63 to delay the demodulator drive signal by 0.4 milliseconds. Repeat the baseline data readings and record in the table below.

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3.9.1 Low Frequency Phase Sensitivity Test - continued

- (h) Repeat step (g) advancing the demodulator drive by 0.4 milliseconds.
- (i) Return the V demodulator timing to the original R63 setting and repeat the baseline data readings. Record results in the table below.

Low Frequency Phase Sensitivity Results

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Test Case	R Signal	V Signal	ΔV Signal	$\Delta V'$ Signal
Initial Baseline	<u>2.503v</u>	<u>4.000v</u>	<u>2.004v</u>	<u>2.037v</u>
R, 1% delay	<u>2.508v</u>	<u>4.000v</u>	<u>2.011v</u>	<u>2.046v</u>
R, 1% advance	<u>2.419v</u>	<u>4.000v</u>	<u>1.999v</u>	<u>2.031v</u>
Baseline Repeat	<u>2.501v</u>	<u>4.000v</u>	<u>2.003v</u>	<u>2.035v</u>
V, 1% delay	<u>2.500v</u>	<u>3.985v</u>	<u>1.920v</u>	<u>1.947v</u>
V, 1% advance	<u>2.500v</u>	<u>3.847v</u>	<u>1.940v</u>	<u>1.980v</u>
Final Baseline	<u>2.500v</u>	<u>4.001v</u>	<u>2.005v</u>	<u>2.037v</u>

3.9.2 High Frequency Phase Sensitivity Tests

Repeat the tests of paragraph 3.9.1 using the high chopping frequency inputs. Peak the R and V readings prior to recording the baseline data of step (c).

For steps (d) and (e) adjust R58 for a timing change of 0.03 milliseconds.

For steps (g) and (h) adjust the R63 for a timing change of 0.16 milliseconds.

Record all the data in the table below:

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3.9.2 High Frequency Phase Sensitivity Tests - continued

High Frequency Phase Sensitivity Results

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Test Case	R Signal	V Signal	ΔV Signal	$\Delta V'$ Signal
Initial Baseline	<u>2.502V</u>	<u>3.999V</u>	<u>2.015V</u>	<u>2.037V</u>
R, 1% delay	<u>2.473V</u>	<u>3.999V</u>	<u>2.008V</u>	<u>2.047V</u>
R, 1% advance	<u>2.458V</u>	<u>3.999V</u>	<u>1.986V</u>	<u>2.019V</u>
Baseline Repeat	<u>2.501V</u>	<u>3.999V</u>	<u>2.008V</u>	<u>2.034</u>
V, 1% delay	<u>2.501V</u>	<u>3.990V</u>	<u>1.948V</u>	<u>1.965V</u>
V, 1% advance	<u>2.500V</u>	<u>3.991V</u>	<u>1.957V</u>	<u>2.005V</u>
Final Baseline	<u>2.501V</u>	<u>3.999V</u>	<u>2.003V</u>	<u>2.035V</u>

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3.10 Temperature Tests

The purpose of these tests is to evaluate the performance of the signal processing circuitry over a temperature environment.

The breadboard electronics shall be installed in a temperature chamber and interconnected with the sensing head simulator, the load simulator, and the necessary output cabling.

3.10.1 Ambient Temperature Baseline Data - Low Frequency Mode

- (a) Set up the test simulator in the low frequency mode. Install the difference amplifier trim resistors called out in paragraph 3.7.1.
- (b) Adjust the input signal levels for a 2.5 volt R signal and a 2.0 volt ΔV signal with zero scene level. Then vary the scene level to give V signals of 2 and 4 volts. The $(S_1 + R_1)$ and $(S_2 + R_2)$ gain pots should be in the 500 setting. Record all test data below allowing adequate time for readings to stabilize.

BASELINE DATA - Room Temperature

V Output	R Output	ΔV Output		$\Delta V'$ Output	
		Mean	Std Dev.	Mean	Std Dev.
0	2.500	2.501	$\pm .1$	2.029	$\pm .5$
2	2.502	1.997	$\pm .4$	2.028	$\pm .8$
4	2.505	1.995	$\pm .5$	2.029	$\pm .7$

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3.10 Temperature Tests - continued

- (c) With the same conditions as step (b) and with the scene level set for a V signal of 4 volts, vary the (S_1+R_1) and (S_2+R_2) gain pots as shown in the table below and record the test data.

BASELINE DATA - Room Temperature

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	$\Delta V'$ Output
Equal	<u>2.128</u>	<u>2.175</u>	<u>2.128</u>	<u>4.002</u>	<u>2.506</u>	<u>1.994</u>	<u>2.028</u>
+25%	<u>2.138</u>	<u>2.174</u>	<u>2.66</u>	<u>4.002</u>	<u>2.506</u>	<u>1.994</u>	<u>2.028</u>
-25%	<u>1.128</u>	<u>2.174</u>	<u>1.595</u>	<u>4.002</u>	<u>2.506</u>	<u>1.994</u>	<u>2.028</u>
Equal	<u>2.128</u>	<u>2.174</u>	<u>2.128</u>	<u>4.002</u>	<u>2.506</u>	<u>1.995</u>	<u>2.029</u>

3.10.2 High Temperature Data - Low Frequency Mode

- (a) Raise the temperature chamber to a temperature of +100°F, allow to stabilize and repeat the tests of paragraph 3.10.1 recording the data below:

(b) High Temperature Test Data

V Output	R Output	ΔV Output		$\Delta V'$ Output	
		Mean	Std. Dev.	Mean	Std. Dev.
0	<u>2.498</u>	<u>4.002</u>	<u>±.3</u>	<u>2.030</u>	<u>±.5</u>
2	<u>2.500</u>	<u>1.997</u>	<u>±.3</u>	<u>2.028</u>	<u>±1.2</u>
4	<u>2.502</u>	<u>1.994</u>	<u>±.4</u>	<u>2.031</u>	<u>±1.8</u>

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3.10.2 High Temperature Data - Low Frequency Mode - continued

(c) High Temperature Test Data

Gain Setting	(S ₁ +R ₁) rms	(S ₂ +R ₂) rms	(S ₃ +R ₃) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	<u>2.130</u>	<u>2.177</u>	<u>2.130</u>	<u>4.002</u>	<u>2.502</u>	<u>1.994</u>	<u>2.030</u>
+25%	<u>2.061</u>	<u>2.177</u>	<u>2.061</u>	<u>4.002</u>	<u>2.502</u>	<u>1.994</u>	<u>2.028</u>
-25%	<u>1.597</u>	<u>2.177</u>	<u>1.597</u>	<u>4.002</u>	<u>2.502</u>	<u>1.993</u>	<u>2.029</u>
Equal	<u>2.130</u>	<u>2.177</u>	<u>2.130</u>	<u>4.002</u>	<u>2.502</u>	<u>1.995</u>	<u>2.031</u>

3.10.3 Temperature Data - Low Frequency Mode

(a) Lower the temperature chamber temperature to 50°F, allow to stabilize and repeat the tests of paragraph 3.10.1, recording the data below:

(b) Low Temperature Test Data

for setting

V Output	R Output	ΔV Output		ΔV' Output	
		Mean	Std. Dev.	Mean	Std. Dev.
0	<u>2.507</u>	<u>1.999</u>	<u>0</u>	<u>2.027</u>	<u>±.6</u>
71.5	<u>2.509</u>	<u>1.995</u>	<u>±.3</u>	<u>2.025</u>	<u>±1.0</u>
173.2	<u>2.511</u>	<u>1.994</u>	<u>±.6</u>	<u>2.025</u>	<u>±2.0</u>

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3.10.3 Low Temperature Data - Low Frequency Mode - continued

(c) Low Temperature Test Data

Gain Setting	(S ₁ +R ₁) rms	(S ₂ +R ₂) rms	(S ₃ +R ₃) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	<u>2.128</u>	<u>2.177</u>	<u>2.128</u>	<u>4.004</u>	<u>2.511</u>	<u>1.994</u>	<u>2.026</u>
+25%	<u>2.06</u>	<u>2.177</u>	<u>2.06</u>	<u>4.009</u>	<u>2.511</u>	<u>1.992</u>	<u>2.024</u>
-25%	<u>1.596</u>	<u>2.177</u>	<u>1.596</u>	<u>4.009</u>	<u>2.511</u>	<u>1.993</u>	<u>2.025</u>
Equal	<u>2.128</u>	<u>2.177</u>	<u>2.128</u>	<u>4.009</u>	<u>2.511</u>	<u>1.994</u>	<u>2.025</u>

3.10.4 Ambient Temperature Baseline Data - High Frequency Mode

- (a) Set up the test simulator in the high frequency mode. Install the difference amplifier trim resistors called out in paragraph 3.7.2. Repeat the tests of paragraph 3.10.1 at room ambient temperature. Record the data below.

(b) Room Temperature Test Data

74°F 87.1

V Output	R Output	ΔV Output		ΔV' Output	
		Mean	Std. Dev.	Mean	Std. Dev.
0	<u>2.500</u>	<u>2.001</u>	<u>.2</u>	<u>2.024</u>	<u>.0</u>
71.2 2	<u>2.513</u>	<u>1.998</u>	<u>.5</u>	<u>2.011</u>	<u>± .3</u>
172.5 4	<u>2.527</u>	<u>1.997</u>	<u>.5</u>	<u>2.002</u>	<u>± .7</u>

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3.10.4 Ambient Temperature Baseline Data - High Frequency Mode - continued

(c) Room Temperature Test Data

Gain Setting	(S ₁ +R ₁) rms	(S ₂ +R ₂) rms	(S ₃ +R ₃) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	<u>2.157</u>	<u>2.205</u>	<u>2.157</u>	<u>3.999</u>	<u>2.526</u>	<u>1.996</u>	<u>2.002</u>
+25%	<u>2.696</u>	<u>2.205</u>	<u>2.696</u>	<u>4.000</u>	<u>2.526</u>	<u>1.997</u>	<u>1.999</u>
-25%	<u>1.618</u>	<u>2.206</u>	<u>1.618</u>	<u>4.000</u>	<u>2.526</u>	<u>1.990</u>	<u>2.004</u>
Equal	<u>2.157</u>	<u>2.205</u>	<u>2.157</u>	<u>4.000</u>	<u>2.526</u>	<u>1.997</u>	<u>2.003</u>

3.10.5 High Temperature Data - High Frequency Mode

- (a) Raise the chamber to +100°F, allow to stabilize, and repeat the tests of paragraph 3.10.1. Record the test data below.

V Output	R Output	Mean	Std. Dev.	Mean	Std. Dev.
0	<u>2.497</u>	<u>2.000</u>	<u>0</u>	<u>2.023</u>	<u>.3</u>
2	<u>2.510</u>	<u>1.995</u>	<u>.5</u>	<u>2.012</u>	<u>.9</u>
4	<u>2.523</u>	<u>1.992</u>	<u>.5</u>	<u>2.003</u>	<u>2.1</u>

(c) High Temperature Test Data

Gain Setting	(S ₁ +R ₁) rms	(S ₂ +R ₂) rms	(S ₃ +R ₃) rms	V Output	R Output	ΔV Output	ΔV' Output
Equal	<u>2.158</u>	<u>2.207</u>	<u>2.158</u>	<u>3.997</u>	<u>2.523</u>	<u>1.992</u>	<u>2.003</u>
+25%	<u>2.696</u>	<u>2.207</u>	<u>2.696</u>	<u>3.996</u>	<u>2.523</u>	<u>1.993</u>	<u>2.001</u>
-25%	<u>1.618</u>	<u>2.207</u>	<u>1.618</u>	<u>3.990</u>	<u>2.523</u>	<u>1.984</u>	<u>2.004</u>
Equal	<u>2.158</u>	<u>2.207</u>	<u>2.158</u>	<u>3.995</u>	<u>2.523</u>	<u>1.993</u>	<u>2.004</u>

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3.10.6 Low Temperature Data - High Frequency Mode

(a) Lower the chamber temperature to +50°F, allow to stabilize, and repeat the tests of paragraph 3.10.1. Record the test data below:

(b) Low Temperature Test Data

V Output	R Output	ΔV Output		$\Delta V'$ Output	
		Mean	Std. Dev.	Mean	Std. Dev.
0	<u>2.501</u>	<u>1.997</u>	<u>0</u>	<u>2.017</u>	<u>.5</u>
2	<u>2.514</u>	<u>1.992</u>	<u>.4</u>	<u>2.003</u>	<u>.7</u>
4	<u>2.527</u>	<u>1.989</u>	<u>.6</u>	<u>1.991</u>	<u>1.4</u>

(c) Low Temperature Test Data

Gain Setting	(S_1+R_1) rms	(S_2+R_2) rms	(S_3+R_3) rms	V Output	R Output	ΔV Output	$\Delta V'$ Output
Equal	<u>2.157</u>	<u>2.206</u>	<u>2.157</u>	<u>4.000</u>	<u>2.528</u>	<u>1.989</u>	<u>1.992</u>
+25%	<u>2.696</u>	<u>2.206</u>	<u>2.696</u>	<u>4.000</u>	<u>2.528</u>	<u>1.992</u>	<u>1.991</u>
-25%	<u>1.618</u>	<u>2.206</u>	<u>1.613</u>	<u>4.000</u>	<u>2.528</u>	<u>1.978</u>	<u>1.987</u>
Equal	<u>2.157</u>	<u>2.206</u>	<u>2.157</u>	<u>4.000</u>	<u>2.528</u>	<u>1.989</u>	<u>1.992</u>

(d) Return the test chamber to room ambient temperature and remove the unit.

APPENDIX H

MAPS BRASSBOARD FINAL REPORT

MAPS BRASSBOARD FINAL REPORT

PREPARED FOR

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1.0 INTRODUCTION

This report describes work done by Barringer Research Limited (BRL) towards the development of the measurement of air pollution from space experiments (MAPS), initially intended to be flown on the Nimbus G space satellite.

This is the final report on work done under Subcontract A39260 RABS to TRW Systems, and under NASA Prime Contract NAS-1-13695. The BRL programme began in December of 1974 with a Phase I conceptual design which ended in March, 1975 with the BRL conceptual design report TR75-250.

The conceptual design arrived at a baseline design approach and the main findings and baseline will be briefly described.

Phase II of the BRL effort was directed towards the detailed engineering design, fabrication, assembly and testing of a brassboard version of the opto-mechanical head of the MAPS sensor.

Phase III of the BRL effort was directed towards the design, fabrication and acceptance testing of a Ground Support Unit (GSU) intended to provide the radio-metric stimulus and calibration optical signals for calibrating the brassboard and all MAPS sensor hardware.

Phase IV of the BRL programme is to provide "follow-on" support activity to aid TRW in data evaluation and brassboard and GSU hardware help.

This report will include the test results obtained in assessing the performance characteristic of the brassboard.

During the course of the programme some changes were made to the original work statement which resulted in less brassboard testing at BRL than initially planned. In addition, there were a number of changes in hardware design, i.e., chopper disc changes, an extra mounting plate for operating the GSU-brassboard independent of the GSU gas cell, etc.

2.0 BRASSBOARD DESIGN AND FABRICATION

2.1 Introduction

The MAPS brassboard optical design layout is shown in Figure 1. Source radiance enters the sensor via objective lens L1. The size of the objective is determined by the desired sensor field of view (4.5 degrees in this case). Radiance from a distant source is imaged in the objective focal plane where a field stop common to all detectors is located. A 45 degree reflective chopper is located adjacent to the field stop.

A relay lens L2 images the objective lens at the aperture stop. L2 also images the sensor field stop through the interference filter IF and the gas cells onto the field lenses L4, L5 and L6 via the beamsplitters BS1 and BS2. The field lenses image the aperture stop and the objective onto the detectors thus avoiding imaging any scene "hot spots" onto the detectors. A second relay lens L3 images via beam recombiner BR1, the reference stop onto the field lenses, coincident with the sensor field stop.

Reference radiation originating at the hot and cold blackbody pair set is chopped at a frequency f_R by the same chopper disc which modulates the scene at frequency f_S . The reflective chopper disc accomplishes this by means of a double annular set of chopping apertures.

2.2 Special Design Features

2.2.1 Balanced Chopper

The chopper disc at chopping frequency f_S alternately introduces radiation to the detectors from the scene and the reflective blackbody. The reflective blackbody radiance was chosen so as to minimize the difference in radiance from the two radiation sources. When the scene radiance and the reflective blackbody radiance are equal the chopper is "balanced" and the electronic signal amplitude is zero.

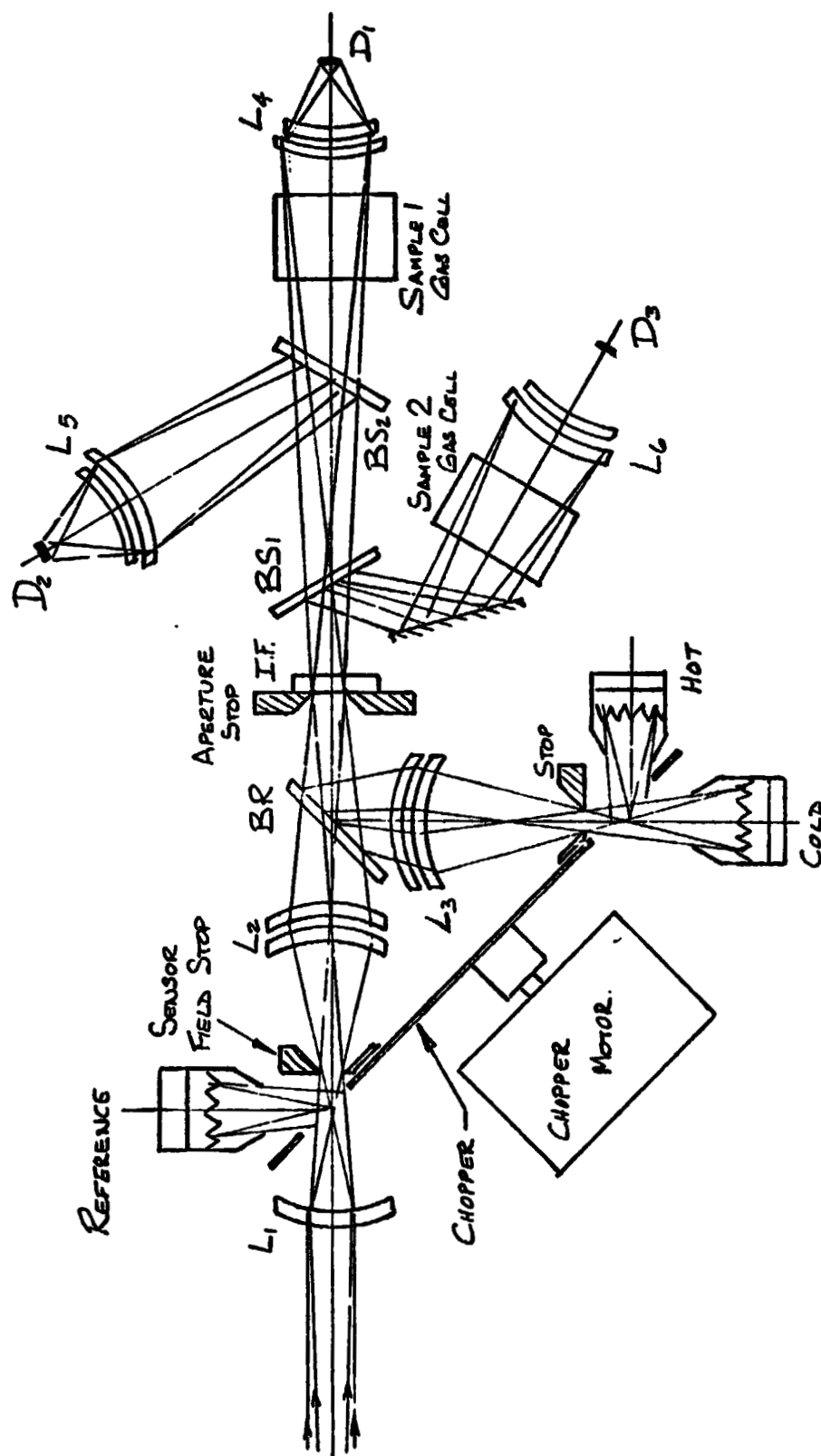


FIGURE 1

(Nevertheless the signal is still developed due to the correlation of incoming target gas with the internal target gas cell).

2.2.2 Reference Blackbodies

The reference blackbodies generate at frequency f_r , an optical signal which is used in an electronic feedback loop to gain control pairs of electro-optical arms (detector pairs 1 and 2 and detector pairs 3 and 2). The optical signal was computed to be adequate when the hot blackbody was at 70°C and the cold at 20°C.

2.2.3 Common Field Stop

The use of a common scene field stop for all three detector arms ensures that each and every detector simultaneously receives energy from a hot or cold spot passing through the sensor field of view.

2.2.4 Beamsplitters and Beam Recombiners

The conceptual design study on beamsplitters and beam recombiners indicated that the spectral and spatial uniformity of the beam recombiner was not critical. However if the beam recombiner was polarizing it was found that the geometrical arrangement of the two beamsplitters would cause the sensor to be polarization sensitive. Thus the beam recombiner was required to be non-polarizing.

The beamsplitters were analysed and it was shown that the spatial and spectral uniformity quality of these were critical. In addition so as to avoid spurious noise due to incident radiation of changing polarization, two possible solutions were analysed:

- (a) two uncoated ZnSe beamsplitters at opposing 30° angles.
- (b) two Ge beamsplitters AR coated on one side and operating one at 20° with the second at 25° in the opposite direction.

2.2.5 Chopper Disc

The chopper disc was chosen to be an aluminum substrate with an overcoat of gold for high reflectivity.

2.2.6 Blackbody Design

Although in the sensor design, spatial uniformity of the source is not critical, the blackbody design attempts to achieve a uniformly high emissivity cavity whose temperature is precisely known.

The shape of the cavity is adjusted to achieve a high effective emissivity. Common shapes which have been used are spherical, conical, cylindrical, grooves, overlapping cones, and honeycombed walled arrays. Because of the difficulty in making high precision radiometry measurements, heavy reliance is placed upon computed emissivity values. Computer calculation techniques to predict cavity emissivities have been developed. Unfortunately, most real blackbodies do not have simple shapes such as those used in computations. Computations have been extended to blackbodies with lids even for nonisothermal cases. Work shows the importance of the cavity length to diameter ratio, being > 2 , the importance of the cavity lid, and the relative insensitivity to the lid emissivity and to the cavity wall emissivity, and the tolerance of the effective emissivity to thermal gradients from the cavity base to the lid entrance. Good thermal contact of the housing lid to the base and heater source assures minimum thermal gradients.

To achieve a uniform temperature cavity surface, a high thermal conductivity wall material is used. Copper has a thermal conductivity about twice that of aluminum, but the difficulty in machining plus the more troublesome special preparation requirement of the surface prior to painting suggests aluminum as being the most suitable material.

The cavity is insulated for operation so as to minimize convective or conductive heat loss which would cause thermal gradients. Measurement of the cavity temperature

must be done with good quality precision thermistors embedded in the cavity walls. Good thermal contact between the thermistors and the cavity is achieved by means of conductive greases of low vapour pressure.

The heat source or sink used for thermal control of the cavity should make good thermal contact over a large surface area of the cavity. A low vapour pressure thermally conductive grease coupling between the cavity and the cavity heat source is used.

The thermal time constant of the cavity is determined by the cavity mass and specific heat, and by the rate of heat input. Proportional temperature control plus a high specific heat material such as copper or aluminum of minimum mass should result in time constants of the order of a few minutes.

TABLE 1

BRASSBOARD LENS PARAMETERS

LENS	MATERIAL	DIAMETER (mm) \pm 1 mm.	CENTRE THICKNESS (mm) \pm 0.1 mm.	RADII OF CURV. (IN.) \pm 0.1%	A.R. COATING
L1 Objective	Ge	50	3.5	2,602, 3.870	OCLI wideband multilayer, 6048005
L2 relay (a)	Ge	35	2.5	1,373, 1.228	ii
lens pair (b) (L3 same)	Ge	35	3.0	2,000, 4.744	
L4, L5, L6					
Field lens (a)	Ge	28	2.5	1.199, 1.625	ii
pair (b)	Ge	23	2.0	0.550, 0.573	

NOTES -- 80 - 50 scratch and dig

-- sphericity to 4 fringes overall, 1 fringe irregularity

-- uniformity stressed by manufacturing in planetary double rotation and masking techniques, and in the case of the field lens a special on-axis rotation used and all carried out in a common coating batch lot

-- 1 mm. of edge used for mounting

3.0 OPTO-MECHANICAL DESCRIPTION

This section is intended as a collection and summary of the specification parameters of the opto-mechanical section of the MAPS brassboard. The mechanical specifications of the various components are not described except in general terms, as these components are well specified in the attached engineering drawing set.

3.1 Optical Lens

The brassboard lenses were procured from OCLI. They are Germanium lenses whose radii of curvature were optimized for best imaging under the distance constraints shown in the mechanical drawings. The actual radii of curvature are given in Table I. Also shown are the diameters, thickness at center, and notes as to scratch and dig, sphericity and AR coatings.

3.2 Beamsplitter Parameters

The four beamsplitters for the brassboard are all Ge, AR coated on one side. One set of two beamsplitters were AR coated to peak at 4.6 microns at 20 degrees angle of incidence, while the other set of two were AR coated for 11.2 microns and 20 degrees angle of incidence.

3.3 Beam Recombiner

A single beam recombining was designed for operation at both the 4.6 and 11.2 micron operating wavelengths. This beam recombining, as stated earlier, needed to be non-polarizing. The beam recombining is a 2 mm thick Germanium substrate, AR coated on both sides with a broadband coating, and in addition, one side overcoated with a polka dot pattern of gold dots so as to achieve a dot area to clear area ratio of 15/85. The beamsplitter parameters are also summarized in Table II.

3.4 Interference Filters

The interference filters were specified by NASA and the parameters for the OCLI filters supplied to BRL for the brassboard tests at 4.6 and 11.2 microns are specified in Table III.

TABLE II

BEAMSPLITTER PARAMETERS

BEAMSPLITTER	MATERIAL	DIAMETER mm. \pm .1	THICKNESS mm. \pm .1	SURFACE FINISH
4 beamsplitters	Ge	35	1	A.R. coated (for 22 ^o operation) on one side only (1) one set of 2 A.R. coating peaked at 4.6 microns (2) one set of 2 A.R. coatings peaked at 11.2 microns
1 beam recombiner	Ge	40	2	Aluminized with a "polkadot" array of 0.61 \pm .80 mm. radius for a net aluminized area of 15%. The dots being in linear rows and in a pattern so as to give isosceles triangles of 3 mm. sides. Both sides A.R. coated with wideband OCLI multilayer 6040005

NOTE: -- wedge angles \leq 3 minutes of arc
 -- 80 - 50 scratch and dig
 -- 4 fringe flatness, 1 fringe inequality
 -- 1 mm. of edge used for mounting

TABLE III

INTERFERENCE FILTER PARAMETERS

FILTER	λ PEAK	HALF BANDWIDTH (μ) (H.BW)	SLOPE	AVERAGE TRANS. OVER HBW	THICKNESS	MATERIAL
CO	4.671 μ	0.151 μ	0.766% 0.858%	70%	.0382"	Silicon
NH ₃	11.132 μ	1.028 μ	0.98% 0.73%	60%	.040" .040"	BLKR-ZNS B.P.-G.e.

3.5 Gas Cells

The CO and NH₃ gas cells were provided to BRL by TRW. The brassboard required two different cells of each gas. The CO gas cell used 1 mm thick sapphire windows for 4.6 micron transmission while the Ammonia cells used 1 mm Ge windows for 11.2 micron transmission. The cells were assembled according to a gold bonding technique of attaching the windows to the body of the cell.

The cell parameters for the cells used in the brassboard tests at BRL are given in Table IV.

3.6 Detectors

The PbSe thermoelectrically cooled detectors for CO detection and the pyroelectric detectors for NH₃ detection are specified later in the results section as these parameters are used to reduce the data.

3.7 Optical Efficiency Budget

The overall optical transmissions of the MAPS sensor depend on all of the individual components in the optical path. These components are illustrated schematically in Figure 3.1. The optical efficiency of each detector arm is different. The summary of the transmission factors for the individual components, and the net transmission for each arm are given in Table V. The individual component transmissions are taken from vendor supplied data on the components, or witness pieces.

3.8 Mechanical Mounts

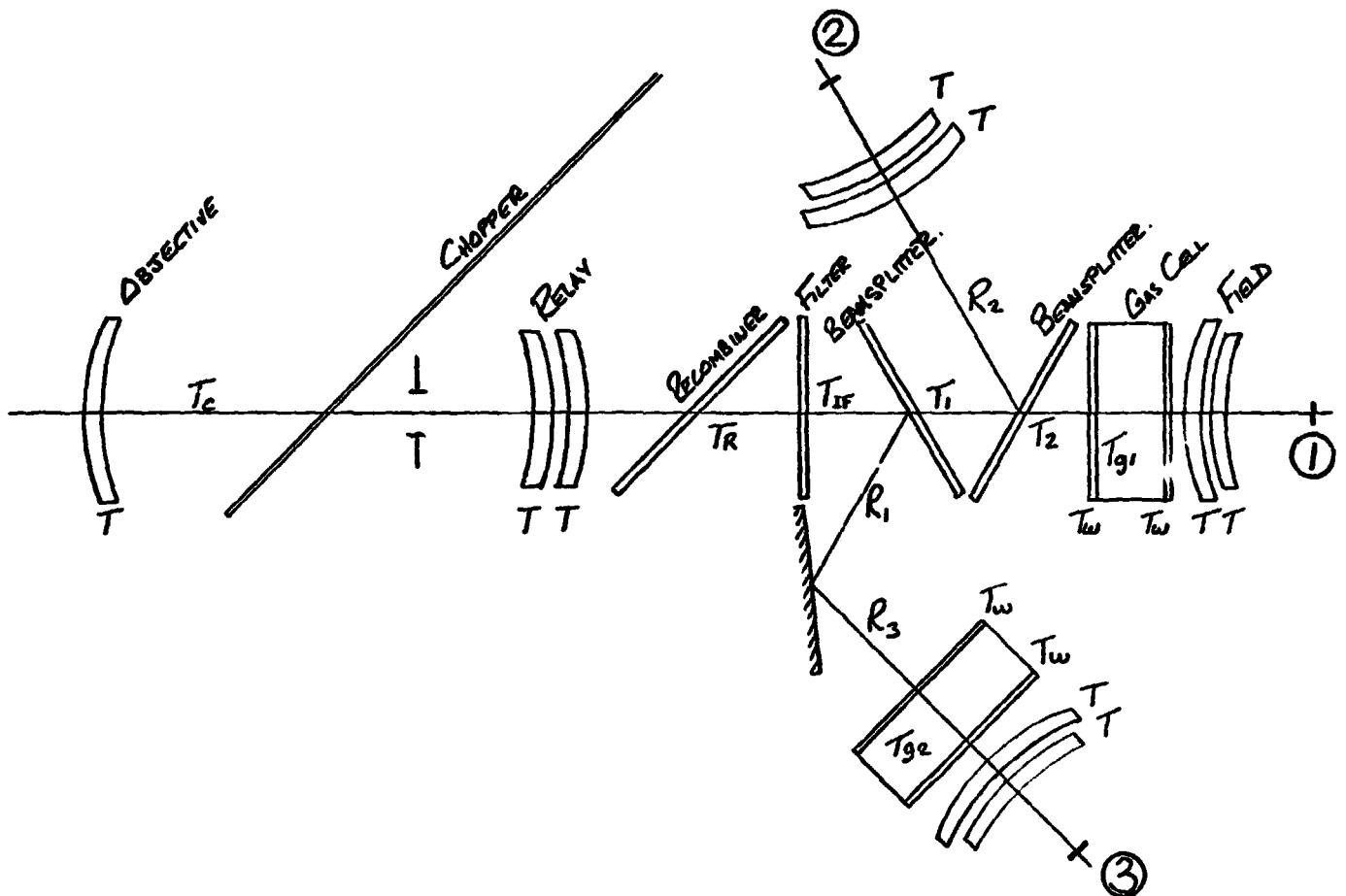
The individual optical components were attached to a flat aluminum baseplate by means of individual component mounts. This design allowed a good deal of flexibility for testing each component. The included drawing set details the design of each of the

TABLE IV

GAS CELL PARAMETERS

GAS	CONCENTRATIONS	WINDOW THICKNESS	WINDOW MATERIAL	AVERAGE TRANSMISSION
CO	HIGH	1.0	Sapphire	.62
CO	LOW	1.0	Sapphire	.68
NH ₃	HIGH	1.0	Ge	.41
NH ₃	LOW	1.0	Ge	.47

TRANSMISSION BUDGET NOMENCLATURE



SYSTEM TRANSMISSION

$$\textcircled{1} \quad K_1 = T^5 T_c T_R T_{IF} T_1 T_2 T_w^2 T_{g1}$$

$$\textcircled{2} \quad K_2 = T^5 T_c T_R T_{IF} T_1 R_2$$

$$\textcircled{3} \quad K_3 = T^5 T_c T_R T_{IF} R_1 R_3 T_w^2 T_{g2}$$

FIGURE 3.1

TABLE V

OPTICAL TRANSMISSION BUDGET

COMPONENT	TRANSMISSION (11μ)	TRANSMISSION (4.6μ)
T	0.96	0.97
T _C	0.96	0.96
T _R	0.91 x 0.85	0.90 x 0.85
T _I	0.65	0.70
R ₁	0.38	0.35
T ₁	0.61	0.63
T ₂	T ₁	T ₁
R ₂	R ₁	R ₁
R ₃	0.95	0.95
T _{W1}	0.48	0.75
T _{g2}	0.85	0.83
T _g	0.97	0.91
Efficiency		
T ₁	.070	.109
T ₂	.091	.097
T ₃	.068	.091

mounts. The detector mounts are integral with the field lens mount. The adjustment mechanism that was finally built and is shown in the drawing set was modified at TRW request from the original design submitted to TRW.

3.9 Electronic Components

The MAPS brassboard was taken through a set of tests at BRL prior to delivery to TRW. To perform these tests a set of laboratory electronic equipment was used. A list of this equipment is given in Table VI.

TABLE VI

ELECTRONIC EQUIPMENT LIST

1. Tetronix Oscilloscope Model 502 with camera.
2. Wavetec Waveform Generator, Model 112
3. PAR Lock-in Amplifier Model HR-8
4. PAR Differential Amplifier Model 114
5. 12 Volt Battery.
6. 90 Volt Battery.
7. \pm 15 Volt Power Supply.
8. Anakek 28 Volt Power Supply Model BRM 40-10C
9. Honeywell Chart Recorder Model Electronik 194

4. Brassboard Tests

4.1 OPTICAL ALIGNMENT, IMAGING AND THROUGHPUT OPTIMISATION

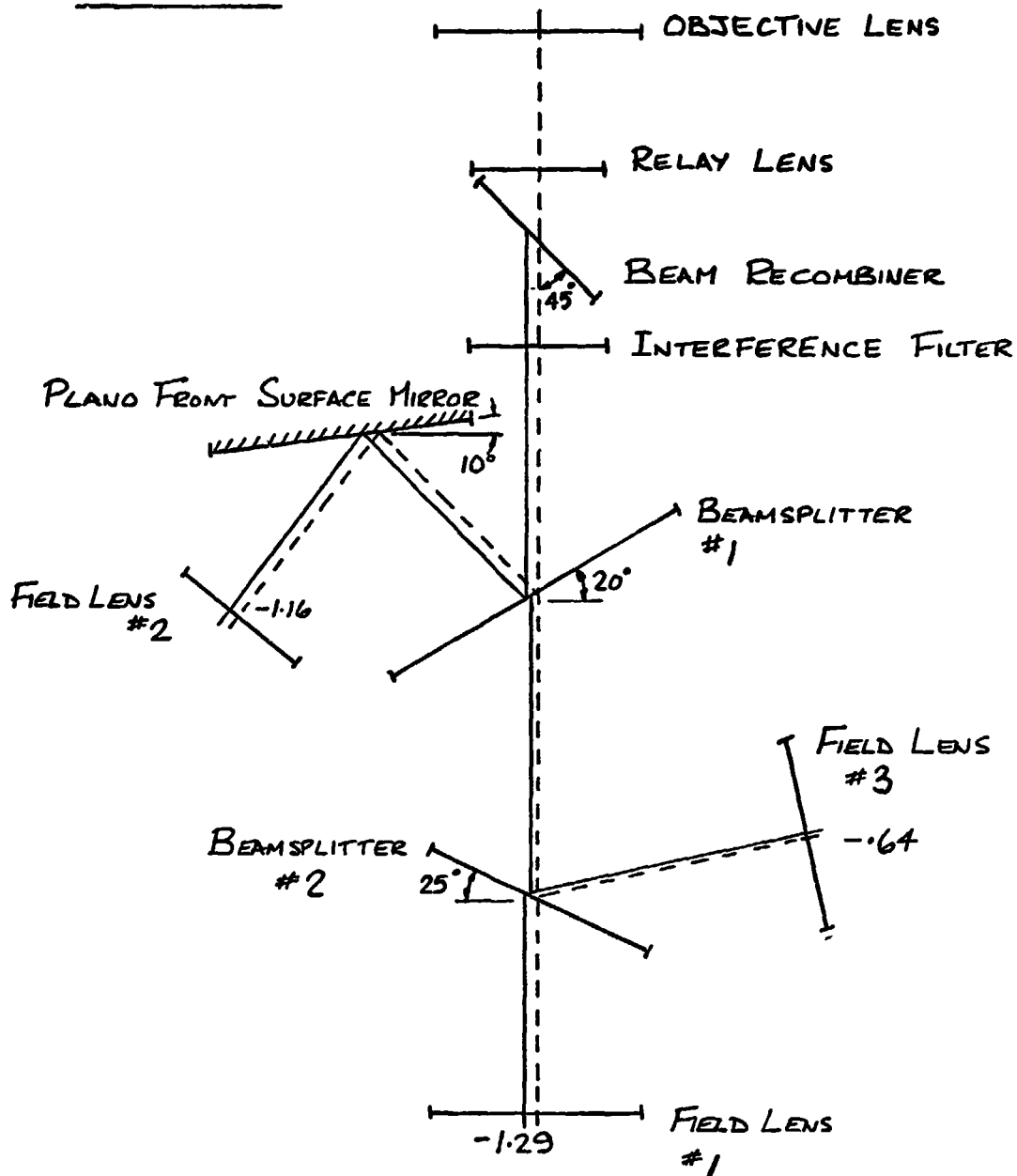
(a) Optical Alignment

Optical alignment of the brassboard was carried out using an He-Ne laser mounted on an adjustable holder (two co-ordinates variable) approximately 10 feet in front of the objective lens holder. The laser beam was aligned such that it was directed along the brassboard optical axis defined to be obtained when the laser beam passes centrally through .010" diameter holes located at the centre of the objective mount and field stop. Orthogonality was assured at the objective and field stop mounts by locating a plano front surface mirror at both mounts respectively and ensuring that the reflected laser beam was coincident with the transmitted beam. The relay lens mount which is an integral part of the field stop mount was considered aligned when the field stop had been aligned. The axial location of the interference filter and aperture stop was found taking into consideration the optical axis displacement due to the beam recombiner. Computed and measured displacements with tolerances for all the optical mounts are shown in Table 4.1. Figure 4.1 shows the computed displacements of the optical alignment. Field lens #1 axial position was found at its calculated axial displacement by measurement from a pinhole located at the centre of the field lens aperture. This displacement was due to the absence of the beam recombiner and two beam splitters. A front surface plano mirror placed at the field lens mount ensured orthogonality of the mount.

The location of the 25° beam splitter mount was obtained using a 25° aluminum jig referenced to a baseline parallel to the optical axis and located on the brassboard base plate. The axial location of field lens #2 was obtained by replacing beam splitter #2 with a front surface plano mirror and adjusting the field lens mount until the laser beam struck the field lens aperture at a location coincident with the computed axial displacement. This location was found by measurement from a pinhole located at the centre of the field lens aperture.

OPTICAL ALIGNMENT CALCULATED DISPLACEMENTS

PLAN VIEW



VERTICAL DISPLACEMENT = 0

SOLID LINE DENOTES LINEAR DISPLACEMENT FROM RAY AXIS (LASER BEAM) i.e. TRUE LOCATION OF OPTICAL AXIS

COMPARISON OF COMPUTED AND MEASURED AXIAL AND ANGULAR DISPLACEMENTS

LOCATION	COMPUTED DISPLACEMENT IN		MEASURED DISPLACEMENT
Field Lens No. 1	Horizontal	-1.29	$-1.25 \pm .25 \text{ mm}$
	Vertical	0	$< \pm 0.3 \text{ mm}$
	Angle	normal	$0^\circ \pm 1^\circ$
Beamsplitter No. 1	Horizontal	-1.24	$-1.0 \pm 0.3 \text{ mm}$
	Vertical	0	$< \pm .3 \text{ mm}$
	Angle	65°	$65^\circ \pm 0.3^\circ$
Field Lens No. 3	Horizontal	-.64	$-0.6 \pm 0.1 \text{ mm}$
	Vertical	0	$0 \pm 0.2 \text{ mm}$
	Angle	normal	$0 \pm 0.3^\circ$
Beamsplitter No. 2	Horizontal		$-1.2 \pm 0.2 \text{ mm}$
	Vertical	0	$0 \pm 0.2 \text{ mm}$
	Angle	70°	$70^\circ \pm 0.3^\circ$
Front Surface Mirror	Horizontal	-1.	$-1.3 \pm 0.3 \text{ mm}$
	Vertical	0	$0 \pm 0.3 \text{ mm}$
	Angle	10°	$10^\circ \pm 0.3^\circ$
Field Lens No. 2	Horizontal	-1.16	$-1.3 \pm 0.3 \text{ mm}$
	Vertical	0	$0 \pm 0.3 \text{ mm}$
	Angle	Normal	$0 \pm 0.3^\circ$
Aperture Stop	Horizontal	-1.16	$-1.15 \pm 0.3 \text{ mm}$
	Vertical	0	$0 \pm 0.3 \text{ mm}$
	Angle	normal	$0^\circ \pm 0.3^\circ$
Beam Recombiner	Horizontal	0	$0.0 \pm 0.3 \text{ mm}$
	Vertical	0	$0.0 \pm 0.3 \text{ mm}$
	Angle	45°	$45^\circ \pm 0.3^\circ$

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Table 4.1

Orthogonality of this field lens mount was again ensured by having the reflected laser beam at the field lens coincident with the transmitted beam. Beamsplitter #1 was installed using a 20° jig again referred to the base plate reference. A front surface plano mirror was then mounted on this beamsplitter mount in order to align the third field lens. The front surface mirror in this arm was located using a 10° jig. The axial position and orthogonality of field lens #3 was found in a similar fashion to #1 and #2.

The beam recombiner mount was located in position at 45° to the laser beam using a 45° jig.

The reference blackbodies were aligned by rotating the brassboard through 180° and aligning the laser beam in such a manner that it was orthogonal to and was transmitted through a .010" pin hole located .045" off the optical axis in the horizontal plane at the aperture stop. The hot and cold blackbodies were aligned by adjusting their respective mounts until the laser beam reflected at 45° by a front surface mirror located at the beam recombiner was coincident with pin holes located at the centres of the blackbody apertures in one instance directly (hot blackbody) and in the second instance after reflection at the chopper disc. Orthogonality of both blackbodies was found as before.

The reflective blackbody was aligned by introducing a .010" pinhole located at relay lens L2 and aligning the laser beam until it was orthogonal to this pinhole. The laser beam reflected from the chopper disc was then used to align the blackbody.

On completion of the optical alignment all mounts were drilled and pinned, prior to removal of the mounts in order to install the optical components and facilitate relocation.

(b) Imaging and Verification of Ray Trace

Field stop Focus

After mounting the objective lens in its mount and relocating mount on brassboard base plate and installation of the chopper disc and cover, the field stop focus was determined using a 3/8 inch diameter, 1/2 inch long hot silicon carbide resistor, located 10 feet on axis in front of the objective lens as the source. The location of the image was obtained using a 0.010 inch pin hole located in front of an InAs detector with the capability of scanning along and perpendicular to the optical axis. Figures 4.2 and 4.3 show the data obtained perpendicular to and along the optical axis. When compared to the optical ray trace the field stop image was found to be 0.6 mm on the beam recombiner side of the field stop physical location. This was initially left "as is". The image depth was found to be $\approx +0.5$ mm and the width $\approx +0.2$ mm.

Aperture Stop Focus

The relay lenses, beam recombiner and field stop were mounted on the base plate and the scanning InAs detector and pin hole were relocated at the aperture stop location. The objective lens was removed and the SiC resistor source was placed behind a 0.040 inch axially located stop at the objective lens position. Directions perpendicular to and along the optical axis were scanned and the data recorded in figures 4.4 and 4.5. The image of this source located in the objective plane was found to be ≈ 1 mm toward the field lens from the aperture stop. This was left "as is". The image depth was found to be $\approx +0.5$ mm and the width $\approx +0.2$ mm.

Field Lens Focus

The InAs detector and pin hole were relocated at the image location of the field stop, i.e., at the field lens #1 position. The hot source was relocated as for the field stop focussing and the objective lens remounted. The results of scanning the 0.010 inch aperture perpendicular to and along the optical axis are recorded in figures 4.6 and 4.7. The various curves in 4.6 are for different settings of the axial co-ordinate. The irregularities of the families of curves show the difficulty in aligning the X-Y scanner on the optical axis. Similar data were recorded for the locations of field lenses #2 and #3.

FIELD STOP FOCUS

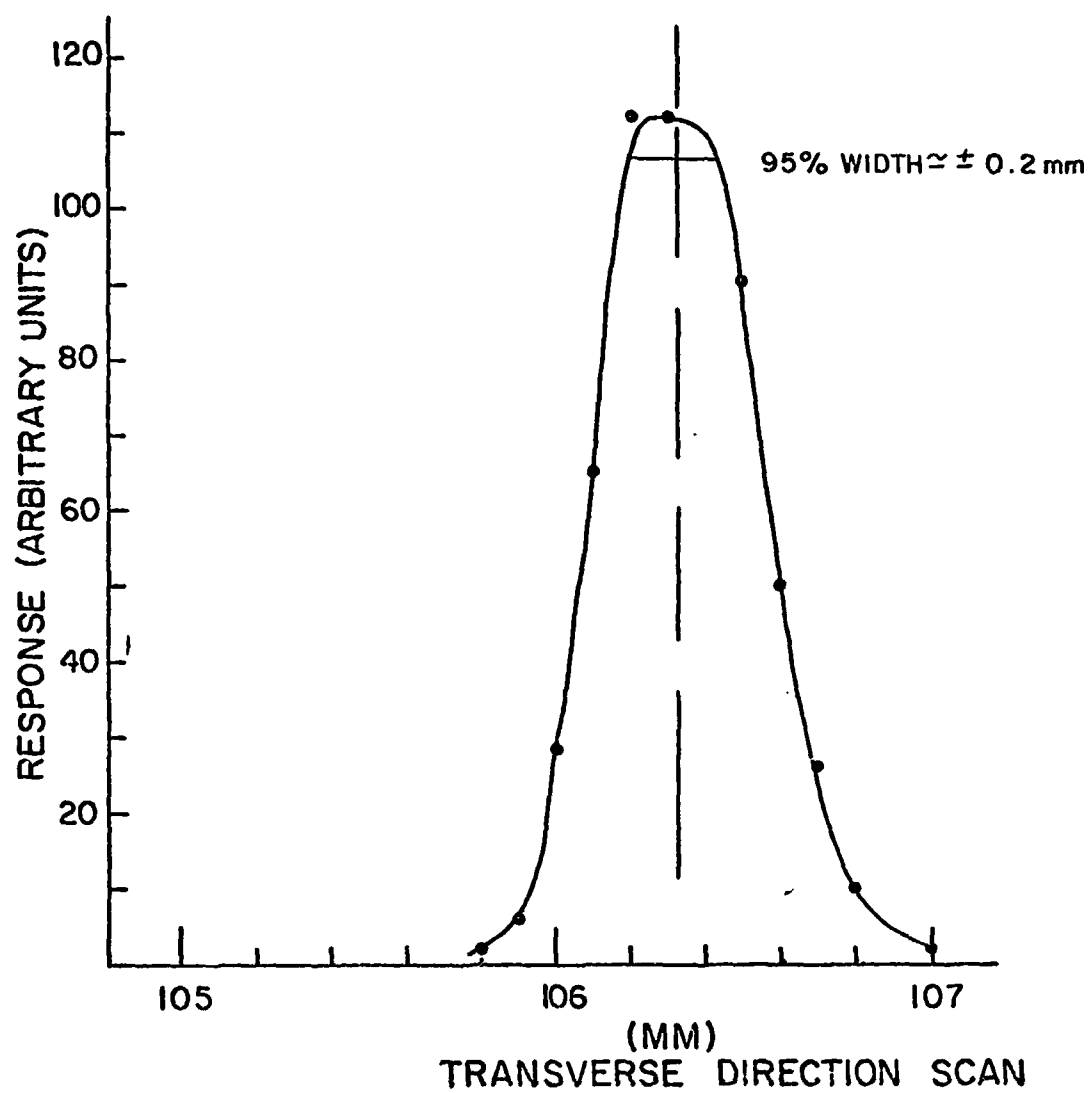


Fig. 4.2

Data obtained using a 0.010 inch scanning pinhole moving perpendicular to the optical axis. The source was a 3/8 inch diameter, 1/2 inch long hot SiC resistor located 10 feet on axis in front of the objective lens.

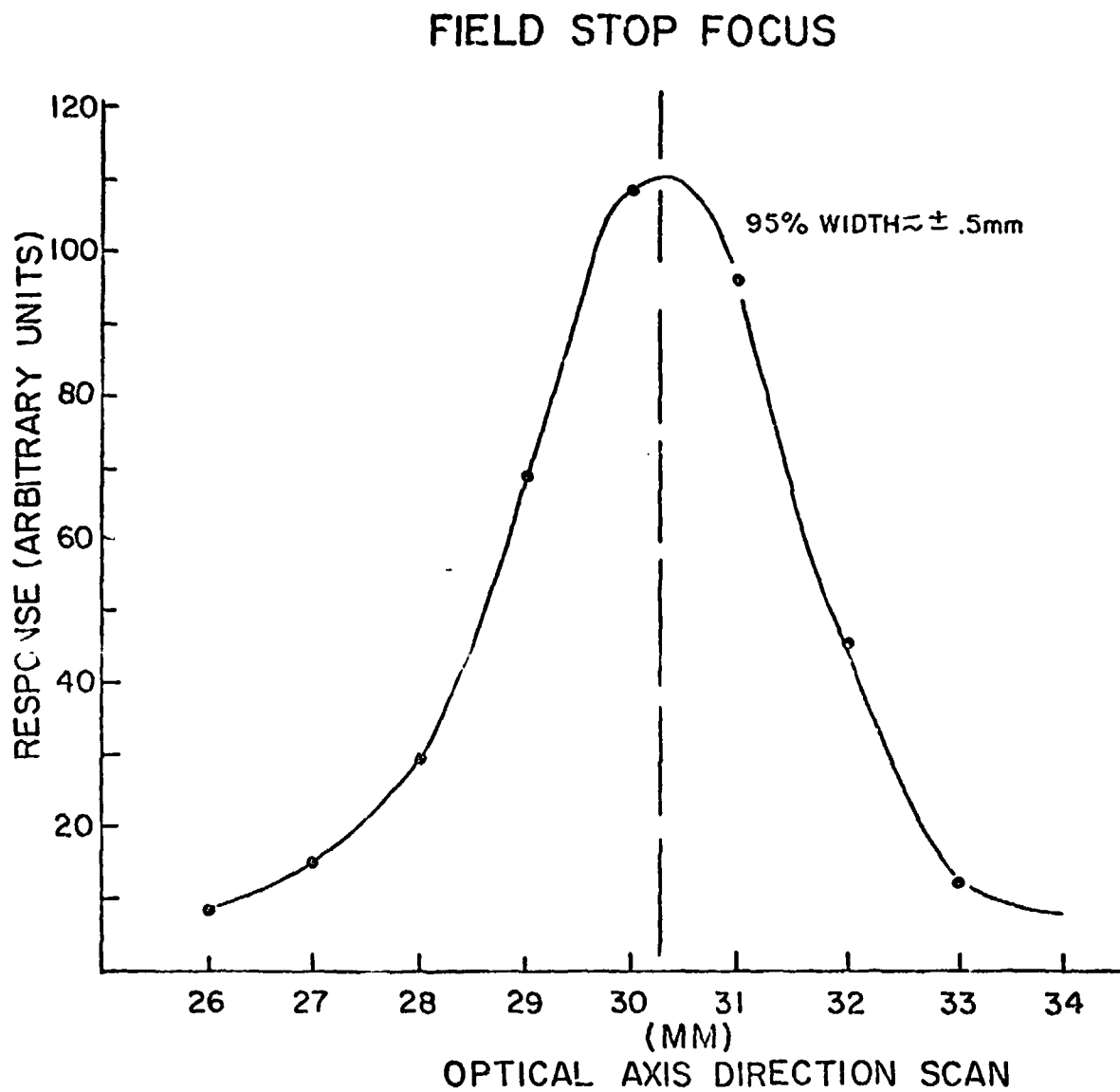


Fig. 4.3

A 0.010 inch scanning aperture moving in the direction of the optical axis at the field stop focus. The source was as in Fig 4.1

APERTURE STOP FOCUS

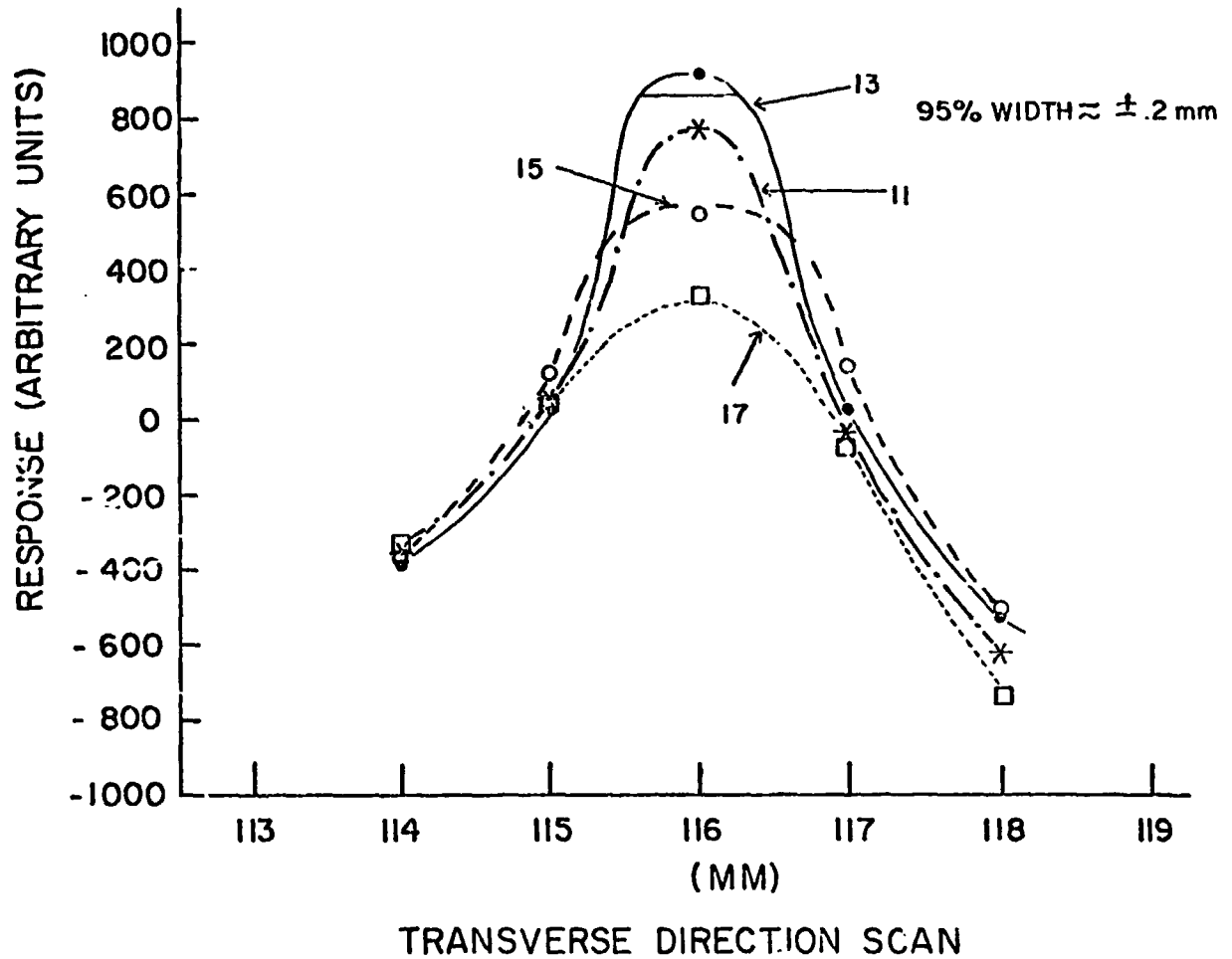


Fig 4.4

Results of pinhole aperture scans at the aperture stop location. The SiC resistor source was located behind a 0.040 inch axially located stop at the position of the objective lens. The X-Y microscope stage mount was scanned in the Transverse direction for a set of values (in mm) for the axial locations. .

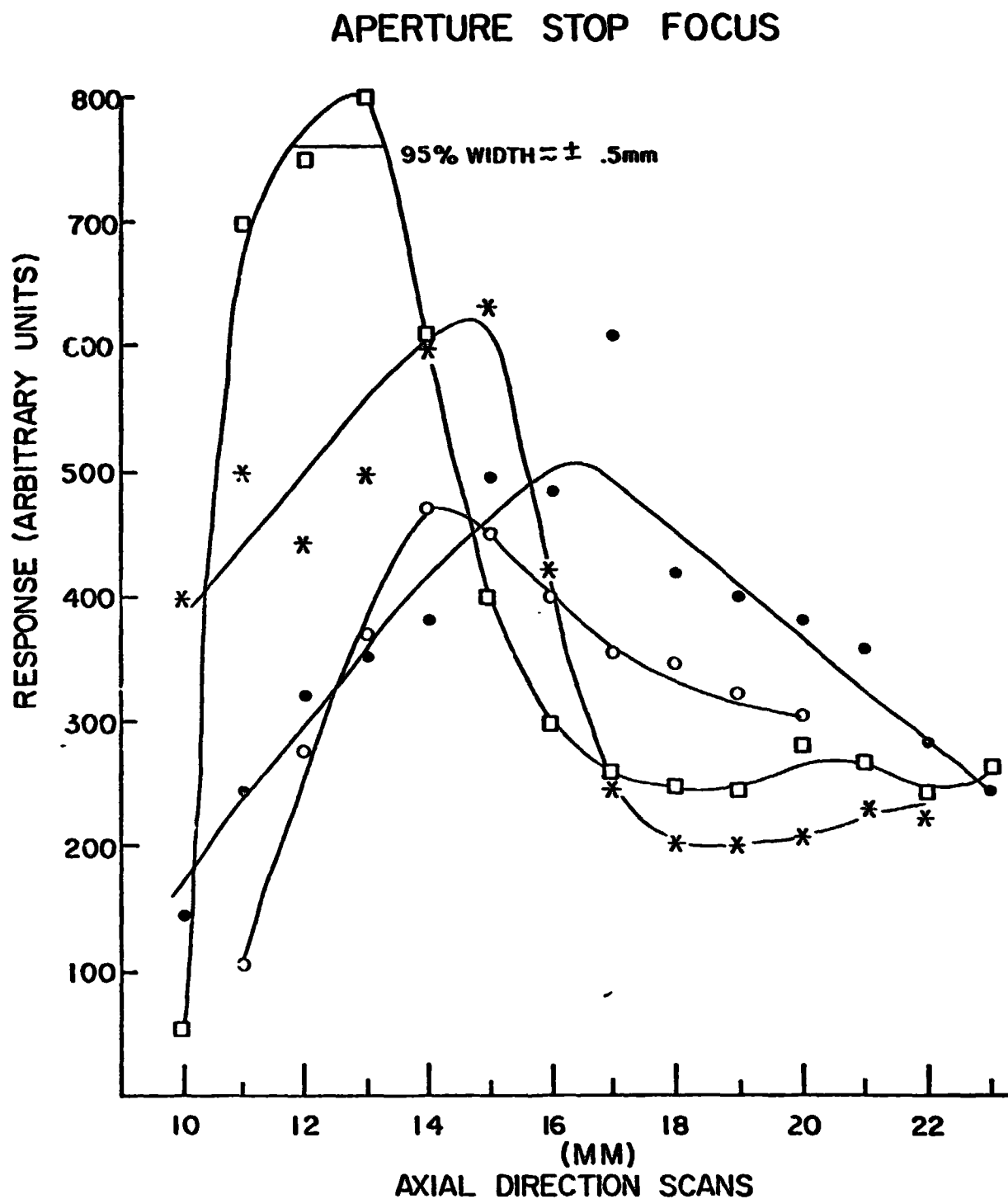


Fig 4.5

Scans of the 0.010 inch pinhole moving in the axial direction at the aperture stop. The source is as for Fig 4.3. The axial scans are for various lateral positions (shown in mm)

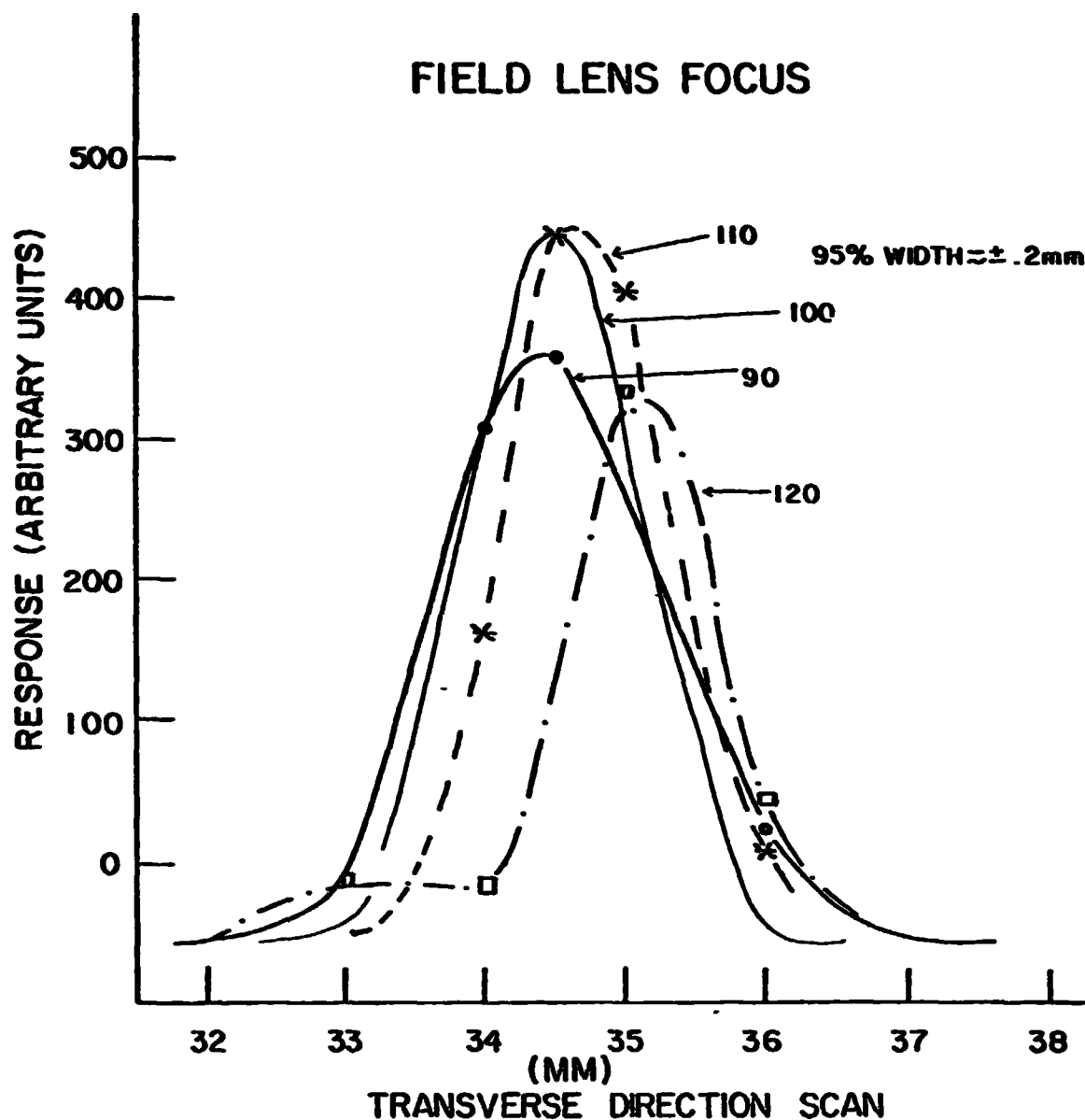


Fig 4.6

Results of scanning the 0.010 inch aperture through the field lens focus position. The source was the SiC resistor located axially 10 feet in front of the objective lens. Thus the focus is a reimaging of the first image located at the field stop. The various curves are for different (in mm) settings of the axial co-ordinate.

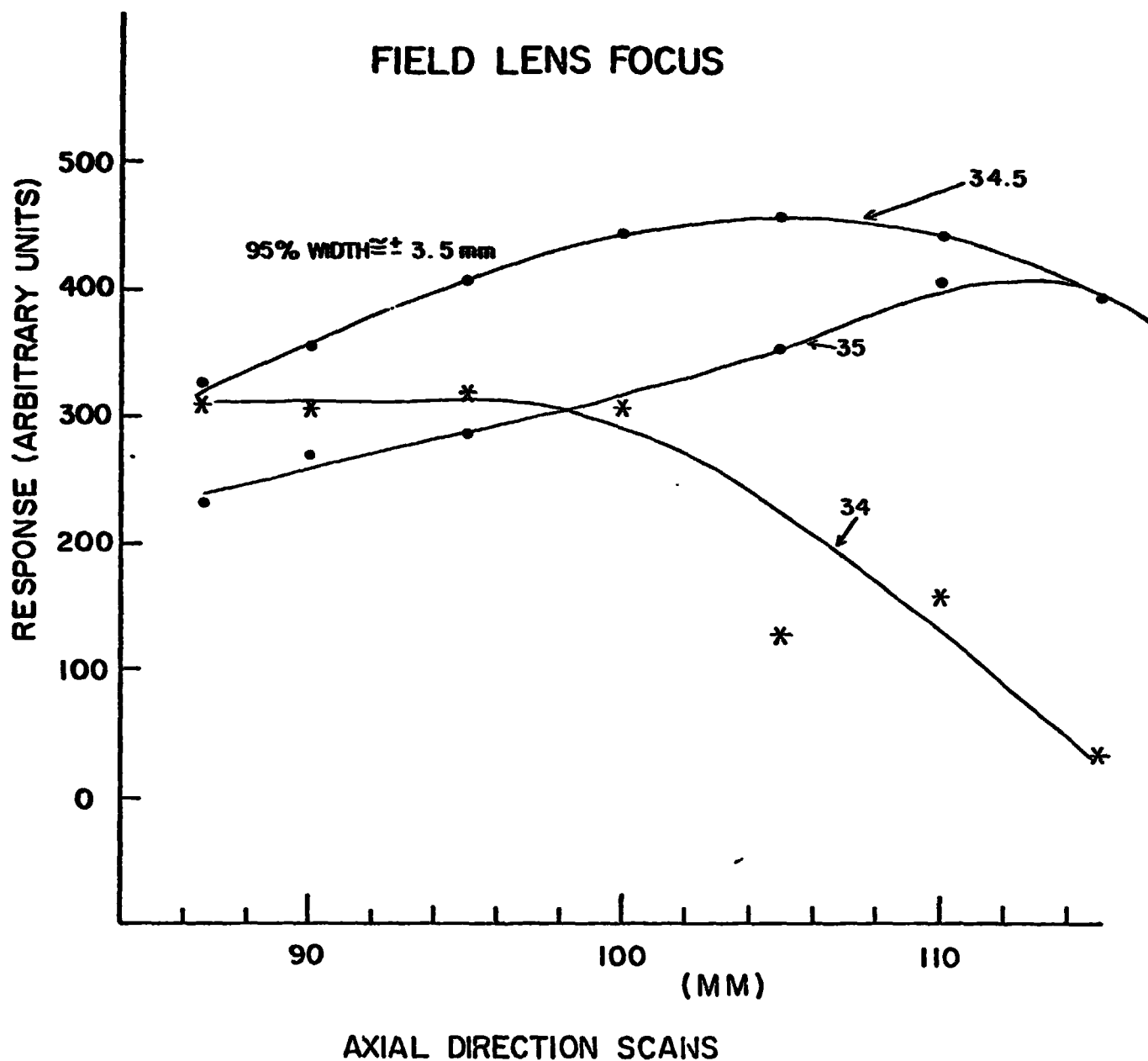


Fig 4.7

Results of the 0.010 inch aperture scans moving in the axial direction for several settings (indicated in mm) of the transverse co-ordinate. The families of curves are not regular because of the difficulty in aligning the X-Y scanner precisely on the optical axis.

(c) Detector Alignment

After locating filed lens positions, all optical components were reassembled and positioned on the brassboard baseplate. Initially, the Pb.Se detectors were installed in their holders and after positioning the CO and N₂ gas cells in their respective optic arms, optimisation of each detector output was attempted. It was not found possible to go through a maximum for any PbSe detector in the direction of the optic axis, however, it was found possible to maximise the detector response in the two directions orthogonal to the optical axis. The detectors were demounted and the mounts modified by removing 0.120" from the rear surface of each, thus enabling the detector to be located closer to the field lens and allowing a maximum position to be found. After discussions with T.R.W. personnel, it was discovered that the PbSe manufacturers' drawings showing the location of the detector flake, were in error, and the detector flake was actually $\approx .100$ inch closer to the detector base than had been expected.

A similar procedure was carried out for the pyroelectric detectors and again it was found necessary to remove .040" from the rear face of each detector mount in order to locate the optimum position where each detector output was found to be able to go through a maximum in all three directions. On location of these positions all detector adjustable mounts were locked to enable relocation on the field lens mount when the PbSe and pyroelectric detectors were interchanged.

The field image was found with no interference filter or gas cells in the brassboard. This image was located at 195.7mm from the rear relay lens surface. The image depth was found to be $\pm 3.5\text{mm}$ and the width $\approx \pm 0.2\text{mm}$. When taking the I.F. and gas cell windows into consideration the field image to relay lens distance would be $\approx 198\text{mm}$, considered too far out of design tolerance. The objective lens was moved $\approx 0.6\text{mm}$ away from the field stop and the field lens image found to be relocated at 190.2mm (excluding I.F. and gas cell windows). The field lens surface is located at 193.7mm from the relay lens. (verification of ray trace) When all the optics are included the field image will be at 192.5mm i.e. the field image will be 1.2 mm ahead of the field lens surface.

4.2 PbSe COOLER TESTS

When the PbSe detectors were received from Opto-electronics it was not found possible to reproduce the cooler temperatures recorded by Opto with the power specified. It was also found that the ambient thermistor resistance values did not correlate with manufacturers data.

Most of the cooling capability was recovered after the detector getters were fired and the variance in the ambient thermistor resistance was later found to be due to the fact that at Opto the thermistor resistance values were recorded with 100 V bias on the detector, resulting in some internal heating.

Gettering was accomplished by passing 5 $\frac{1}{2}$ Amp. A.C. derived from a variable transformer with a transformer acting as a choke to limit the current. The voltage on the Variac was 33 volts and the getters were fired 3 times for 10 seconds each, with a dead period of 3 minutes between each firing.

The time history of each PbSe detector coolers' operating efficiency during testing at BRL is shown in Figures 4.8 - 4.11.

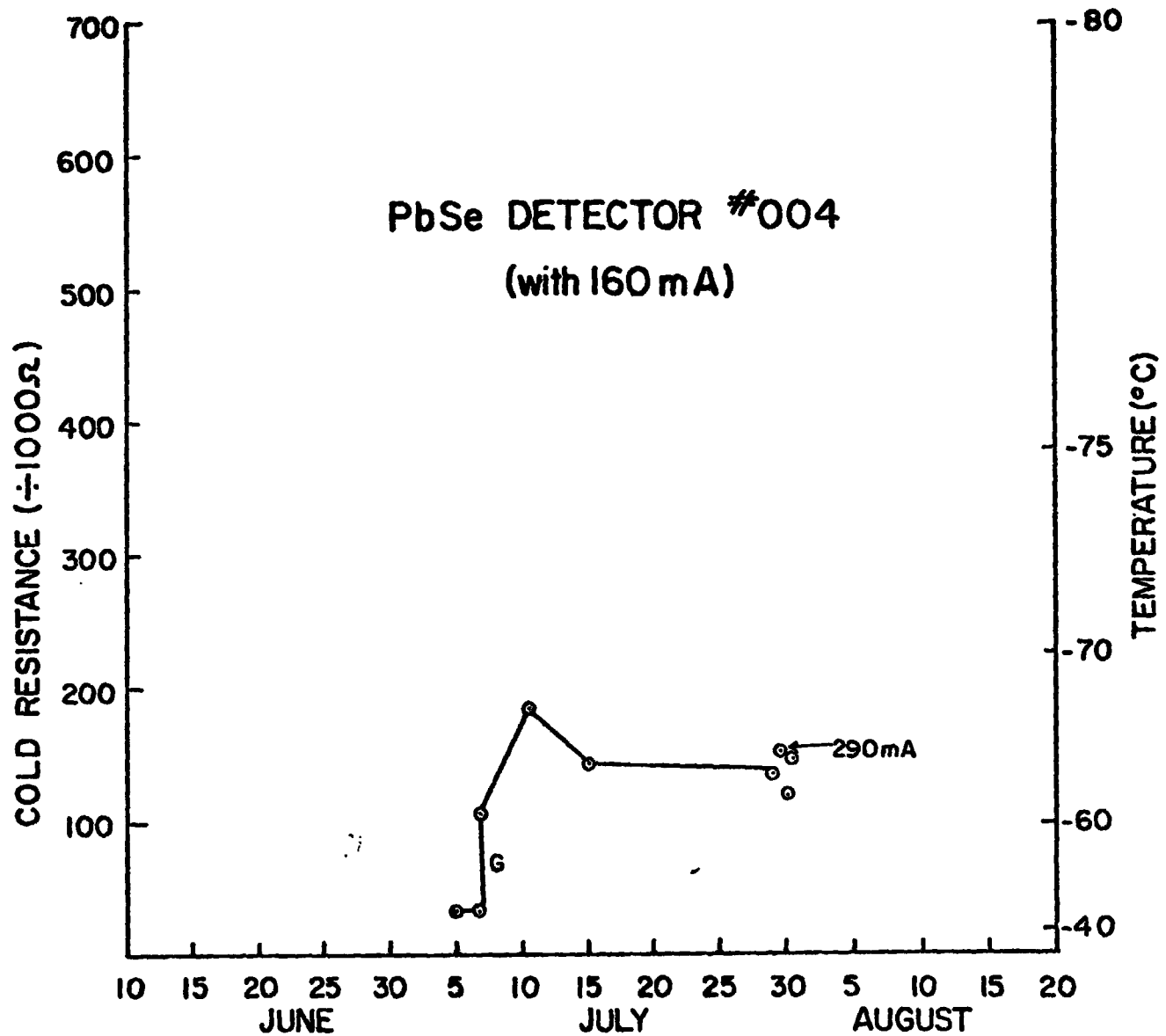


Fig 4.8

The time history of the PbSe detector No.004 cooler, operating efficiency during testing at BRL. Values for the cold resistance of the thermistor were taken for a variety of operating conditions, but the values shown here are for 160 mA of cooler current, unless otherwise shown. The "G" indicates firing the Getters.

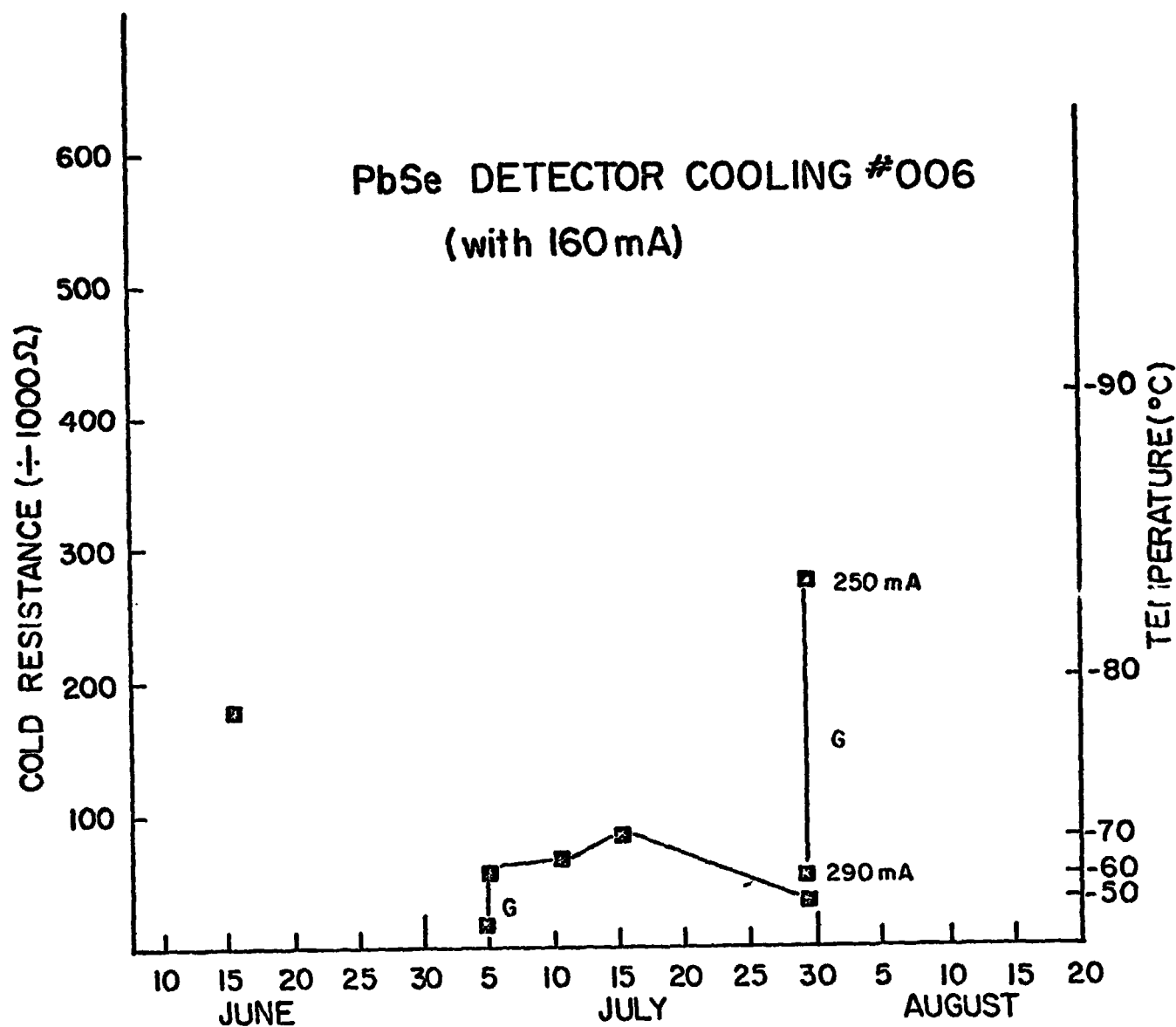


Fig 4.9

The time history of the PbSe detector No. 006, cooler, operating efficiency during testing at BRL. Values for the cold resistance of the thermistor were taken for a variety of operating conditions, but the values shown here are for 160 mA of cooler current, unless otherwise shown. The "G" indicates firing the Getters.

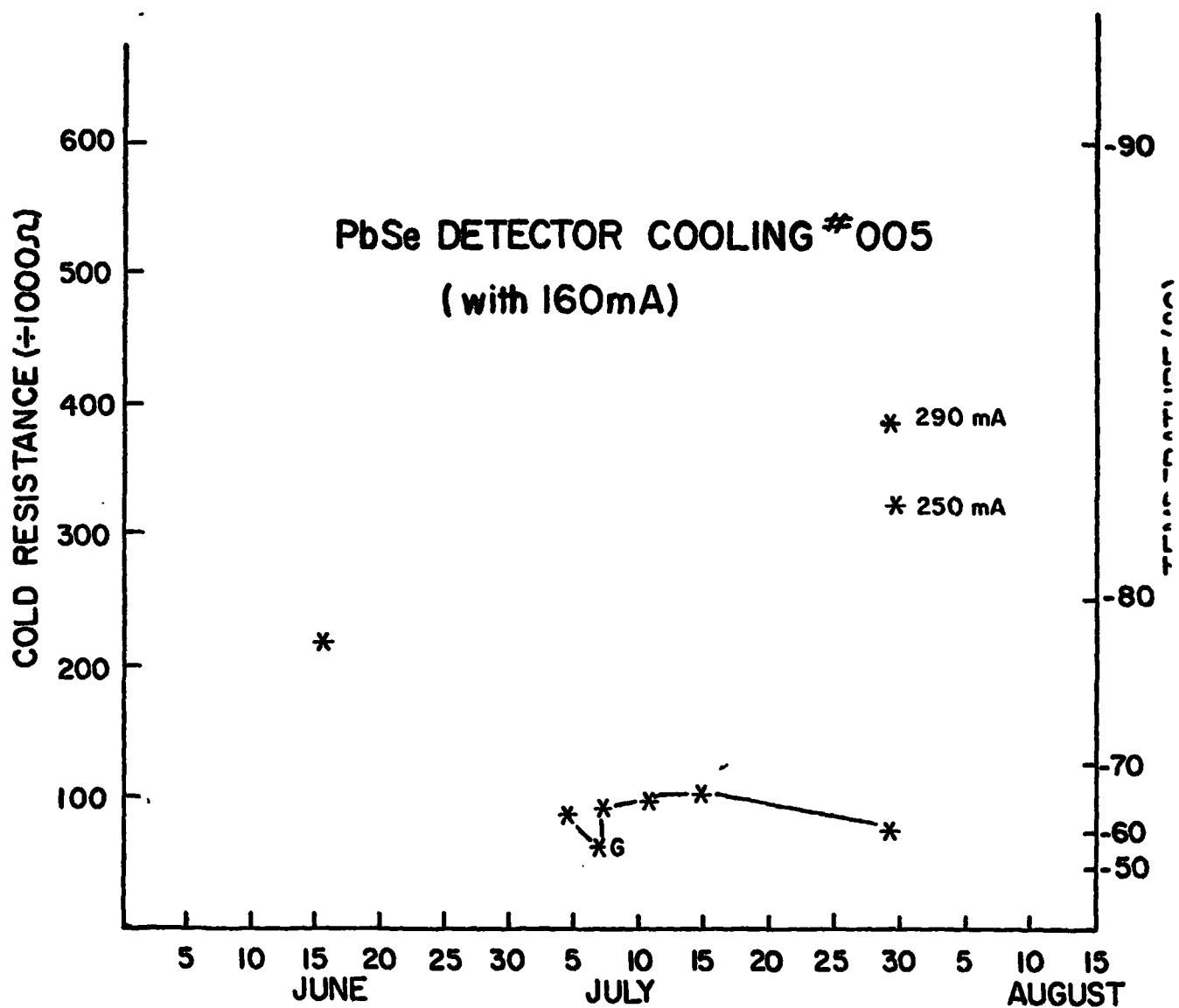


Fig 4.10

The time history of the PbSe detector No.005 cooler, operating efficiency during testing at BRL. Values for the cold resistance of the thermistor were taken for a variety of operating conditions, but the values shown here are for 160 mA of cooler current, unless otherwise shown. The "G" indicates firing the Getters.

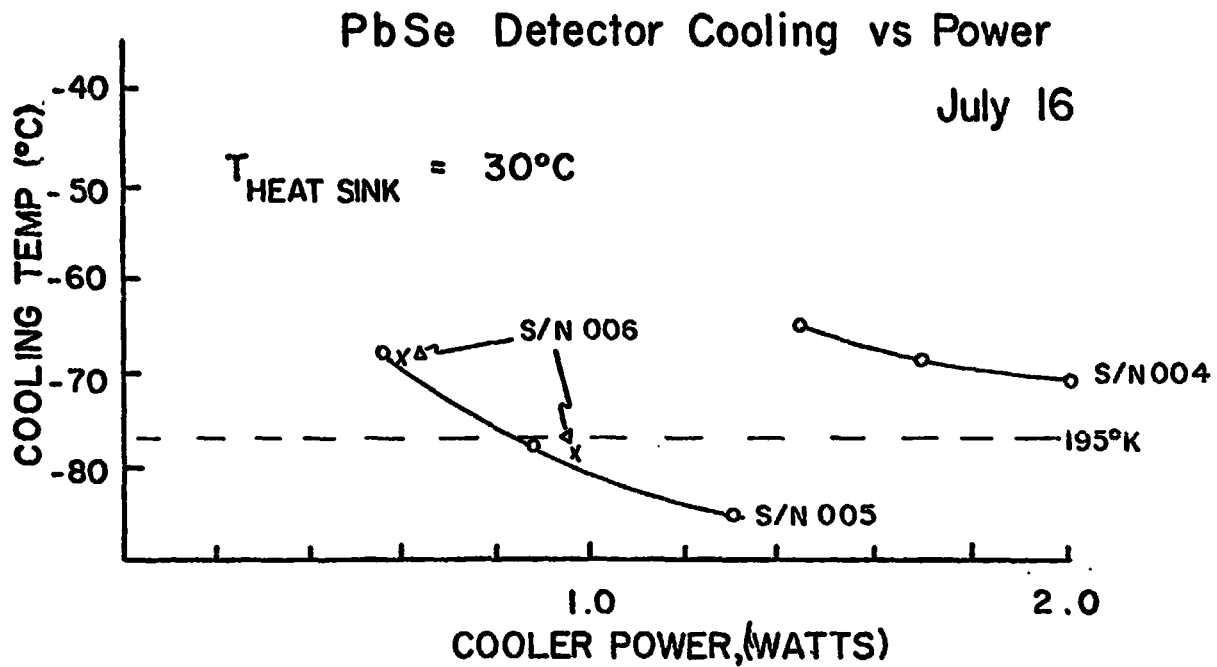


Fig 4.11

PbSe detector cooling efficiency versus power applied to the Thermoelectric heat exchangers. Curves are obtained for a detector heat sink at 30°C .

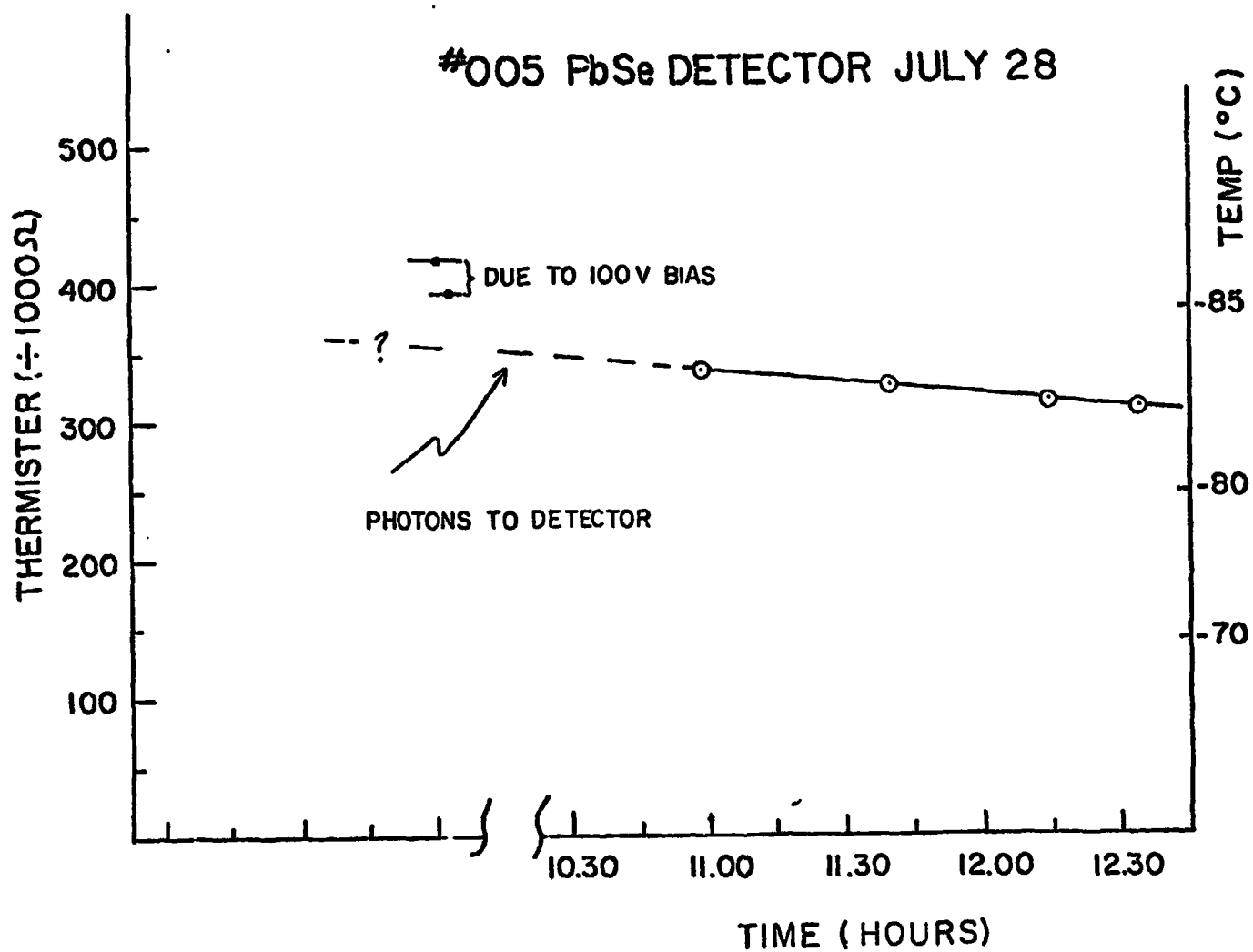


Fig 4.12

PbSe thermoelectric cooler performance versus time. The application of the 100V bias changes the indicated temperature by less than 1°C , and the application of increased photon flux from the blackbody source gave no discernable change in indicated temperature. X

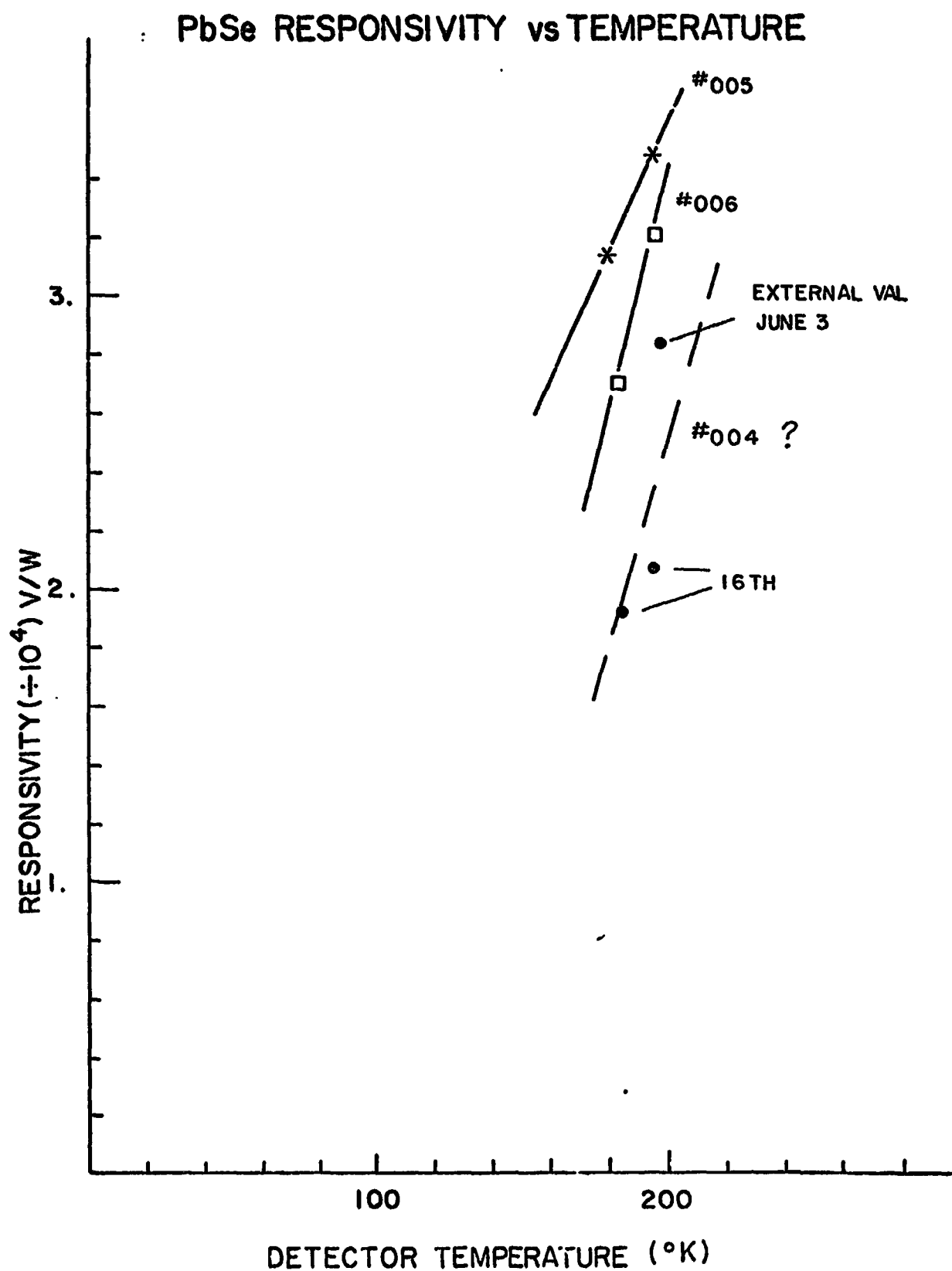


Fig 4.13

Responsivity versus Temperature for the PbSe detectors (data supplied by Opto-electronics).

4.3 HEAT SINKING EFFICIENCY TESTS

The efficiency of the detector heat sinking was evaluated with and without the heat sink strap connected. No. 44033, YSI thermistors were used to monitor the detector base, baseplate and ambient temperatures.

The temperature drift of the baseplate and detector base with the heat sink strap connected was found to correlate with ambient temperature. The detector base without the heat sink strap connected was found to be $\approx 2.5^{\circ}$ C hotter than the base with the strap connected. The difference in the detector cold temperature with and without the heat sink strap was found to be only 0.7° C. Figure 4.14 shows the results obtained during the heat sink efficiency tests.

It would appear that although the heat sink straps do provide an increase in heat sinking efficiency the detectors would operate quite adequately without them. This is not really surprising when one considers that only 2 watts max. has to be dissipated and that the thermal contact between the detector base and mount is very good.

AUG 8/75

--- DENOTES -- NO HEAT SINK STRAP
 // HEAT SINK STRAP

PbSe DETECTOR #005

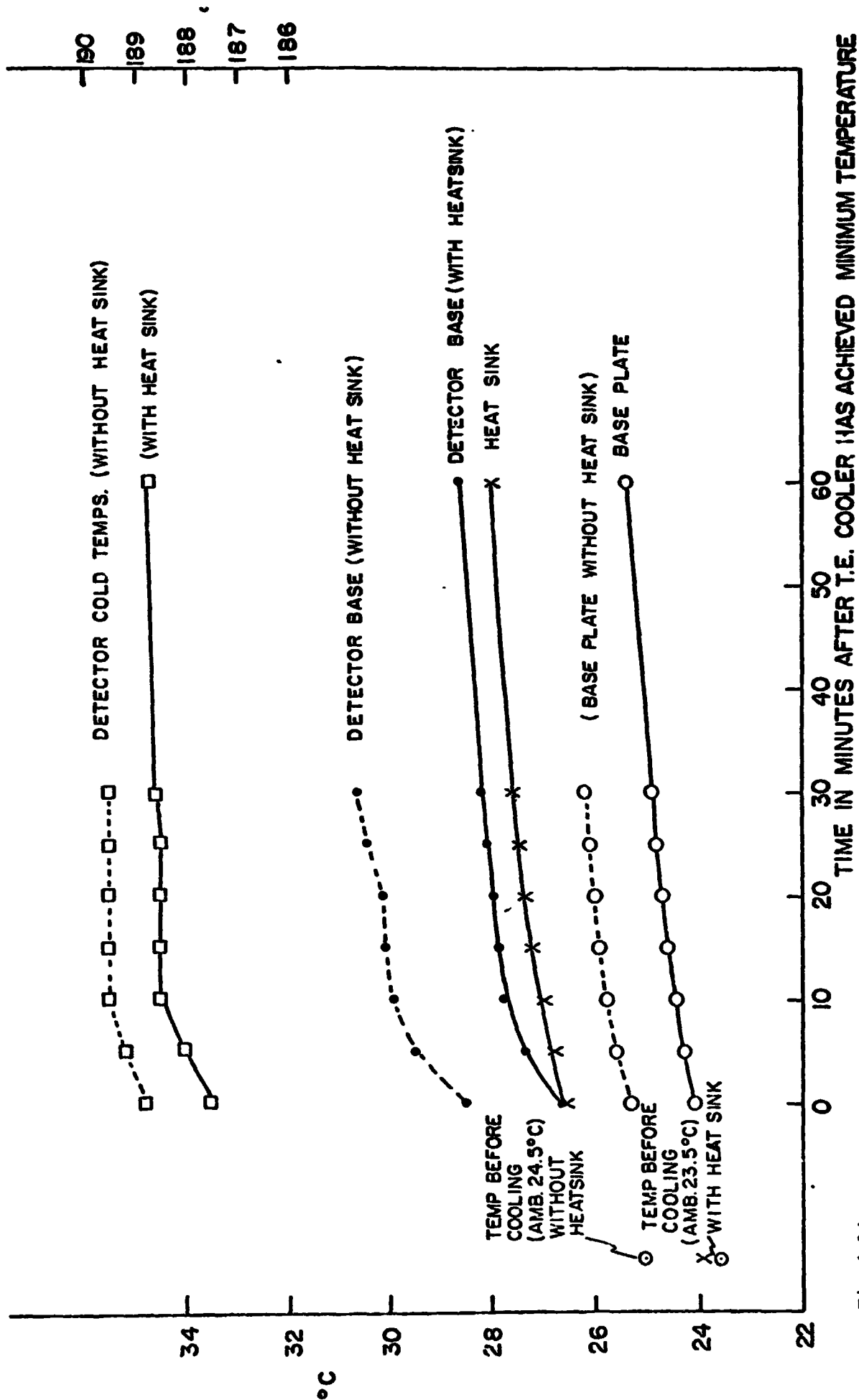


Fig 4.14

4.4 BLACKBODY FABRICATION AND TESTING

The blackbodies were assembled by inserting the body consisting of the machined pyramids in liquid nitrogen and then pressing the body into the cover.

To ensure high emissivity, 3M black paint and appropriate primer were used to paint the blackbodies. Two different techniques were employed, one consisting of swilling the primer followed by the 3M paint around in the blackbody and then suspending the body upside down to allow all excess paint to drip out. The blackbodies were then baked at 275°F for ≈ 30 minutes. When the baking was completed it was found that excess paint which had not been removed from the cavity had partially filled in the base of the pyramids non-black cavity. The second method which was found to give much better results consisted of spraying both the primer and paint on the blackbody and allowing the paint to cure overnight. It is felt that the best approach to take in future would be to spray the blackbody prior to assembling them in their covers, when it will be ensured that the spray carries paint to all sides of the pyramids.

In initial testing of the blackbody with the Tayco heater it was found that the additional heat load provided by the aluminium retaining ring was sufficient to ensure that the thermistor imbedded within the blackbody did not see a temperature greater than 50°C when maximum power (10 watts) was applied to the heater. A teflon ring was fabricated to replace the aluminium retaining ring and heating curves for the blackbody were obtained as a function of time for various fixed levels of heating power. It was found that for maximum heating power a temperature in excess of 100°C could be obtained in less than 20 minutes. Fig. 4.15

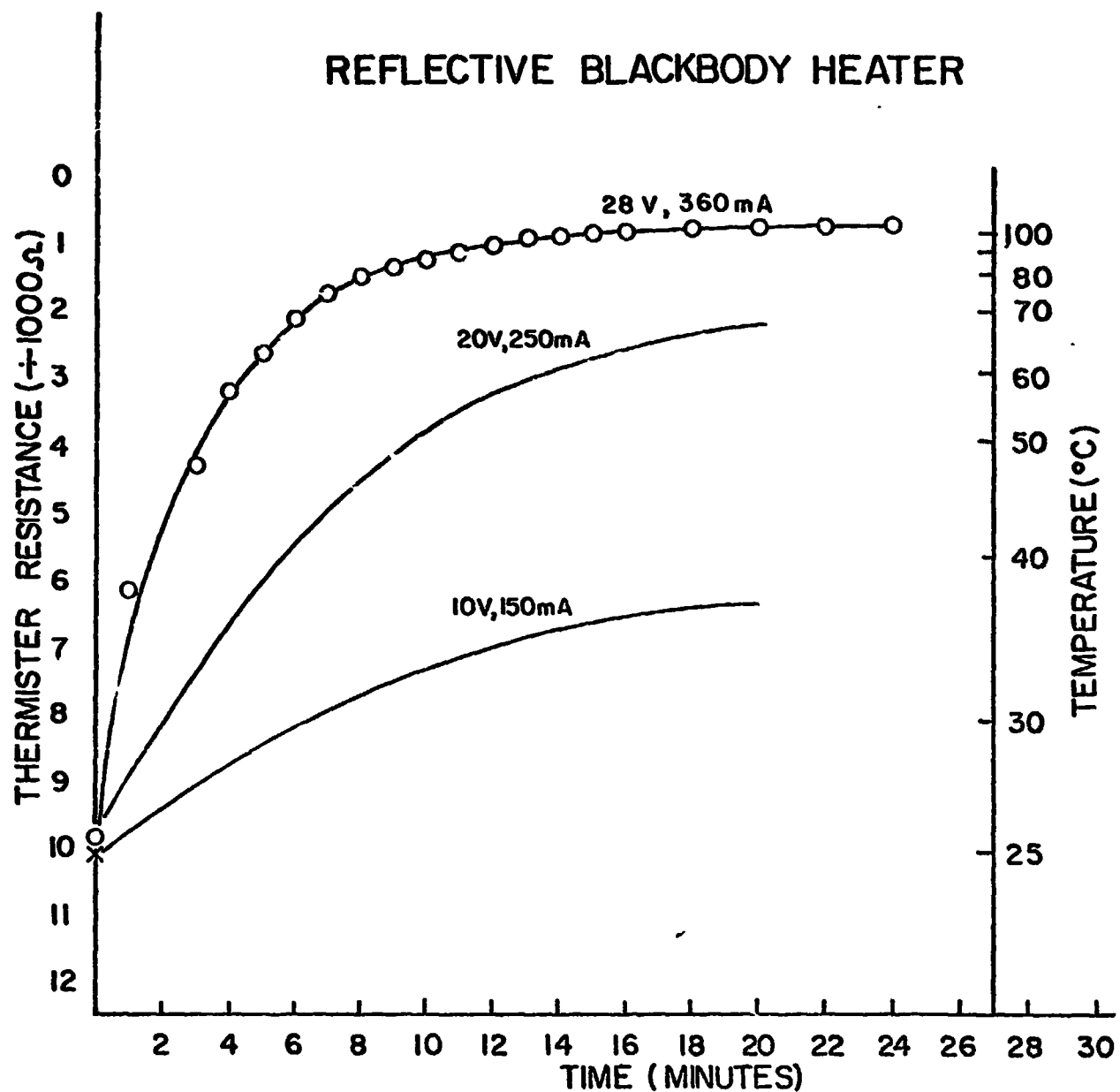


Fig 4.15

Heating curves for the hot blackbody. The curves are obtained as a function of time for various fixed levels of heating power applied to the Tayco heating element.

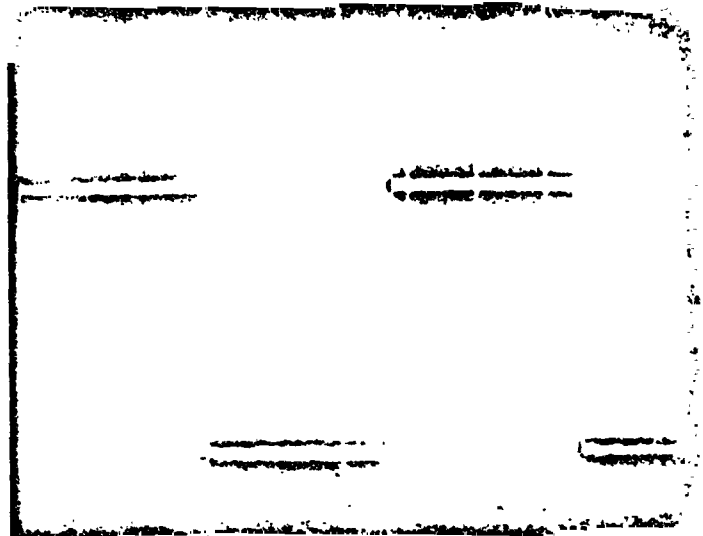
4.5 LED - Phototransistor Tests

L.E.D. - phototransistor tests were carried out for both the reference and signal frequency pick-offs. The L.E.D. used was a G.E. L.E.D. 56 and the phototransistor was an MRD 310. + 10 volts was applied through a 100 Ω resistance to the anode of the L.E.D. and + 20 volts was applied to the collector of the phototransistor. The output signal was picked off across a 100 Ω load resistor.

Oscilloscope records of the outputs of the phototransistors from the L.E.D. phototransistor pairs located on the chopper disc cover are shown in Figures 4.16 and 4.17. Fig 4.16 shows the waveforms for the pair synchronous with the source chopping frequency and Fig 4.17 shows the waveform for the reference blackbody chopping frequency. These records will be of use in evaluating the chopper disc waveforms.

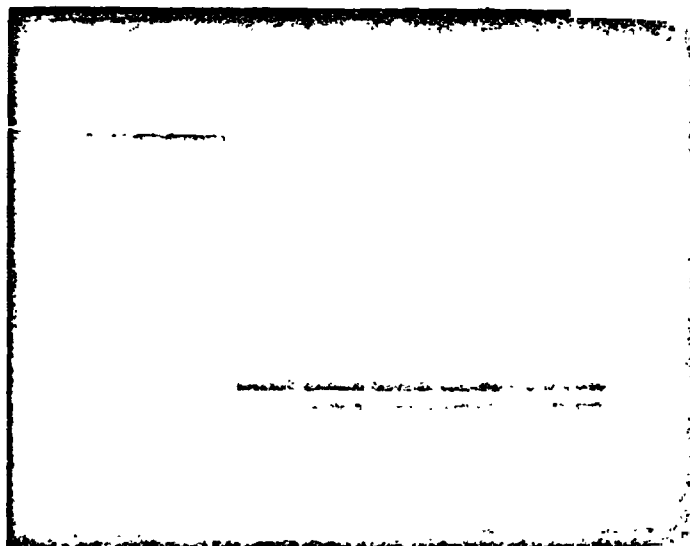
NAPS SYNCHRONOUS SIGNAL WAVEFORM

JULY 8, 1975



20 mV/cm.

2 mSec/cm.



20 mV/cm.

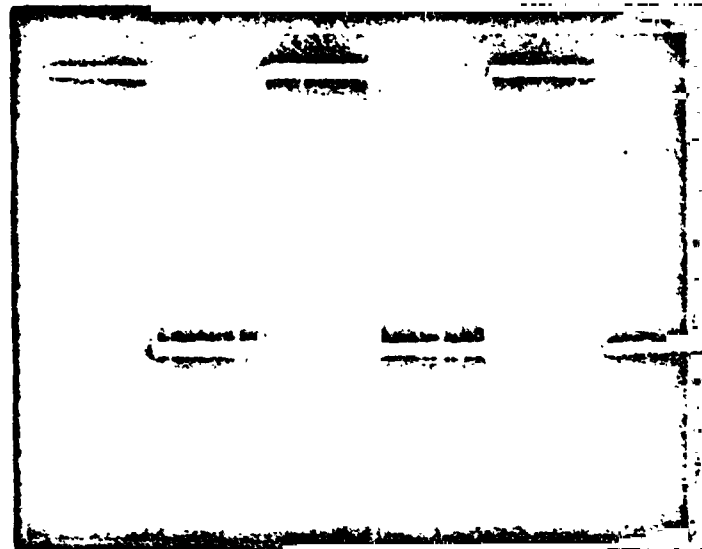
1 mSec/cm.

Oscilloscope records of the outputs from the phototransistors of the LED - phototransistor pairs located on the chopper disc. These records are for the pair synchronous with the source chopping frequency. The records are to be used in evaluating chopper waveforms. The LED's had 10 volts applied and the phototransistors had 20 V on the collector.

FIGURE 4.16

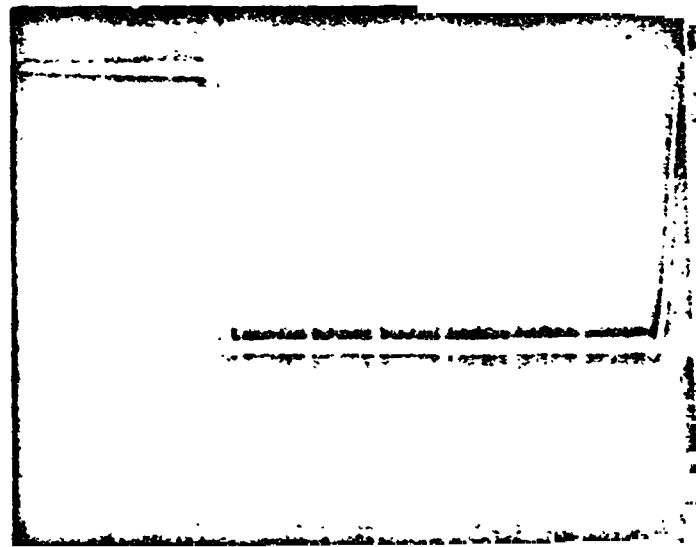
MAPS SYNCHRONOUS REFERENCE WAVEFORM

JULY 8, 1975



20 mV/cm.

2 mSec/cm.



20 mV/cm.

0.5 mSec/cm.

Oscilloscope records of the LED - phototransistor chopper waveforms for the reference blackbody chopping frequency. The LED - phototransistor conditions are as for Figure 4.18.

FIGURE 4.17

4.6 Scene and Reference Signal Evaluation

The PbSe and pyroelectric detector and preamplifier output waveforms were examined using the Eppley blackbody as the scene target. From Figures 4.18 and 4.19 the outputs of the PbSe detector and preamplifier and pyroelectric detector and preamplifier at the scene frequency, for source and reflective blackbody temperatures as noted may be evaluated and the respective chopping efficiency determined through the bandpass of the preamplifier. Figures 4.20 and 4.21 show the composite detector waveforms, source and reference frequencies, for the source temperatures noted.

Optical crosstalk between the scene and reference frequencies was evaluated by monitoring the differential output from preamplifiers #1 and #2 via a P.A.R. differential amplifier and lock-in amplifier with the output $V_1 - V_2$ balanced at zero. $V_1 - V_2$ was recorded via a Honeywell chart recorder.

With the Eppley blackbody set at 33.41°C Av. for the five platinum resistance thermometers the output $V_1 - V_2$ at the scene frequency was monitored while the temperature of the hot reference blackbody was cycled to 64°C and allowed to cool down to ambient 31°C .

No optical crosstalk was apparent on the output at the scene frequency while the amplitude of the reference frequency was varied. Similarly while monitoring the differential reference signal with the hot reference blackbody at 51.5°C and cycling the scene amplitude from 33.41°C to 84.11°C and down again no crosstalk was apparent between the scene and reference frequencies.

PbSe DETECTOR SIGNAL WAVEFORMS

AUGUST 8TH, 1975

#005

1 mSec/cm.
100 mV/cm.



Source 30.81°C
Reflective B. Board
27.95°C

2 mSec/cm.
50 mV/cm.



Source 30.7°C
Reflective B. Board
28.0°C

FIGURE 4.18

PYROELECTRIC WAVEFORM DETECTORS

AUGUST 7TH, 1975

#12243

10 mS/cm.

200 mV/cm.



SIGNAL WAVEFORM

Source 36.54°C

Reflective B. Body

27.74°C

5 mS/cm.

200 mV/cm.



SIGNAL WAVEFORM

Source 45.73°C

Reflective B. Body

26.3°C

100 mS/cm.

200 mV/cm.



REFERENCE WAVEFORM

Cold B. Body 28°C

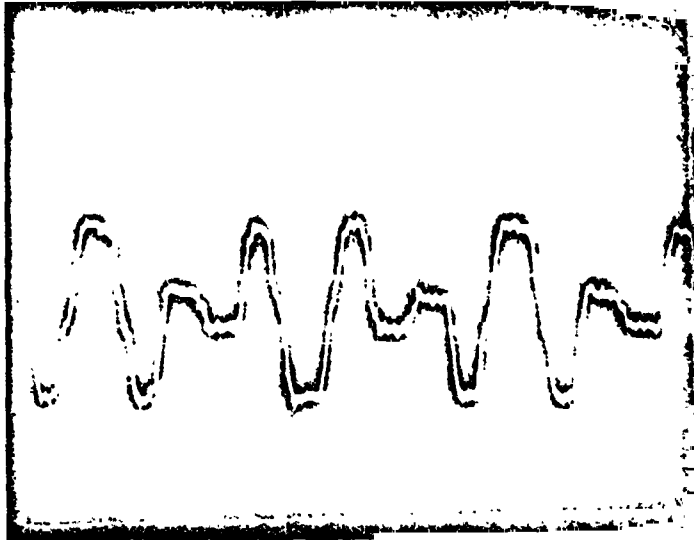
Hot B. Body 74.81°C

FIGURE 4.19

PYROELECTRIC DETECTOR COMPOSITE WAVEFORMS

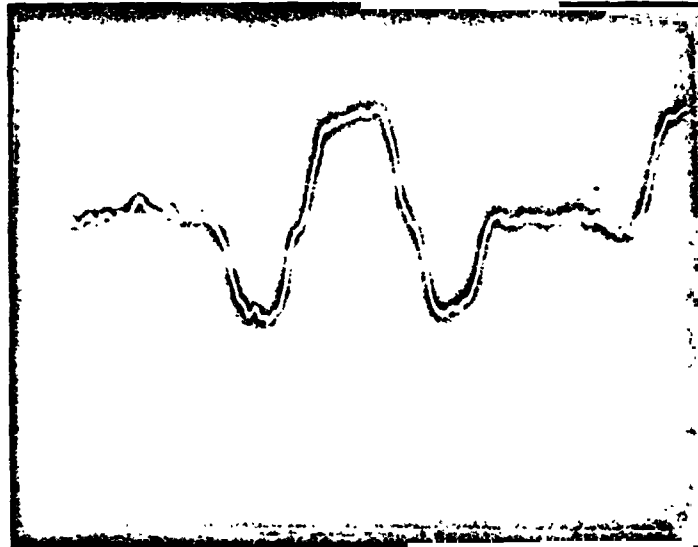
AUGUST 7, 1975

20 mSec/cm.
500 mV/cm.



Source 36.52°C
Reflective B. Body
28°C
Cold B. Body
28.2°C
Hot B. Body
74.81°C

100 mSec/cm.
500 mV/cm.



Source 39.4°C
Reflective B. Body
27.6°C
Cold B. Body
27.74°C
Hot B. Body
74.81°C

100 mSec/cm.
200 mV/cm.



Source 36.53°C
Reflective B. Body
28°C
Cold B. Body
28°C
Hot B. Body
75°C

FIGURE 4.20

PbSe DETECTOR COMPOSITE WAVEFORMS

AUGUST 8TH, 1975

#005

5 mSec/cm.
200 mV/cm.



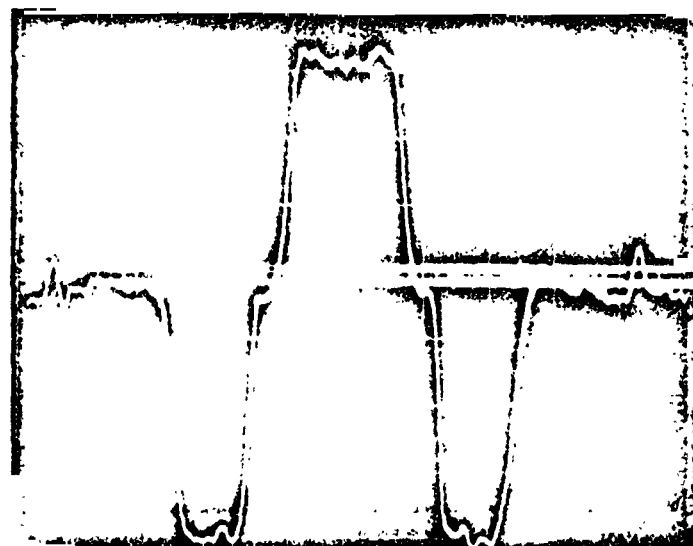
Source 31.17°C
Reflective B. Body
27.9°C
Cold B. Body
27.9°C
Hot B. Body
46.9°C

1 mSec/cm.
100 mV/cm.



Source 30.97°C
Reflective B. Body
27.95°C
Cold B. Body
27.95°C
Hot B. Body
47°C

1 mSec/cm.
100 mV/cm.



Source 31.88°C
Reflective B. Body
27.7°C
Cold B. Body
25°C
Hot B. Body
45.9°C

FIGURE 4.21

4.7 Preamplifier Check-out

The TRW supplied PbSe and pyroelectric preamplifiers were consecutively installed on the brassboard connected to their respective detectors and pre-amplifier outputs evaluated. On the PbSe preamplifiers it was discovered that a large amount of pick-up was apparent due to the thermistor ground and T.E. cooler ground being connected at the output of the preamplifier rather than the input. This modification was carried out when the pick-up was found to disappear. Two of the pyroelectric preamplifiers were found to be wired incorrectly. The -6 V bias on the detector was absent due to lack of a connection between R_1 and R_2 on the preamplifier (see schematic). When these modifications had been carried out, all preamplifier detector combinations were found to operate satisfactorily. The value of the ferrous preamplifier covers was evaluated and while on one pyroelectric preamplifier, high frequency spikes were evident the presence or absence of the covers did not affect the coherent output of the detector and preamplifier.

PERFORMANCE EQUATIONS

$$\text{Detector noise voltage} = (\text{Out p-p noise}) \times \frac{1}{\text{Crest Factor}} \times \frac{1}{\text{Gain}} \times \Delta f^{\frac{1}{2}}$$

$$(V_{\text{rms}} \text{ Hz}^{\frac{1}{2}}) \quad (1)$$

$$\text{System efficiency } \tau_o \tau_e = \frac{\text{Signal response} \times 2 \times \frac{1}{\text{Gain}}}{\Delta N_{\lambda} \times \text{responsivity} \times \Delta \lambda \times A \Omega} \quad (2)$$

$$\text{NEP} = \frac{\text{noise voltage}}{\text{responsivity}} \quad (\text{watts}) \quad (3)$$

$$\text{NEN} = \frac{\text{NEP}}{A \Omega \tau_o \tau_e} \quad (\text{W cm}^{-2} \text{ sr}^{-1}) \quad (4)$$

$$\text{AF} = \frac{1}{A_v^2} \int_0^{\infty} [A_v(f)]^2 df$$

$$= \pi/2 \cdot f_2 \text{ for 6 db/octave filter} \quad (5)$$

$$D^* =$$

$$D^* = \frac{(A_d \Delta f)^{\frac{1}{2}}}{\text{NEP}} \text{ Cm Hz}^{\frac{1}{2}} \text{ W}^{-1} \quad (6)$$

4.8 NOISE VOLTAGE MEASUREMENTS

Noise voltages were determined for each detector preamplifier combination with modulated energy derived from the Eppley blackbody falling on the detectors. The output from each preamp was taken in turn via a PAR lock-in amplifier to a chart recorder and the peak-to-peak noise voltage determined when all modulated energy was removed from the detectors by blocking each optical arm in turn.

Noise voltages referred to each detector were obtained using equation (1). The peak-to-peak noise was measured from the chart record where the time period considered was $\approx 100 \times$ PAR time constant. In this case the time constant was 1 second and thus peak-to-peak noise over periods of 100 seconds were taken and an average value derived over 5 such periods. Noise from all of the detectors was assumed to be Gaussian and the appropriate crest factor obtained from figure 4.22.

The gain of each preamp was determined by introducing a square wave of known amplitude at the signal frequency into each preamp input and recording the preamp output.

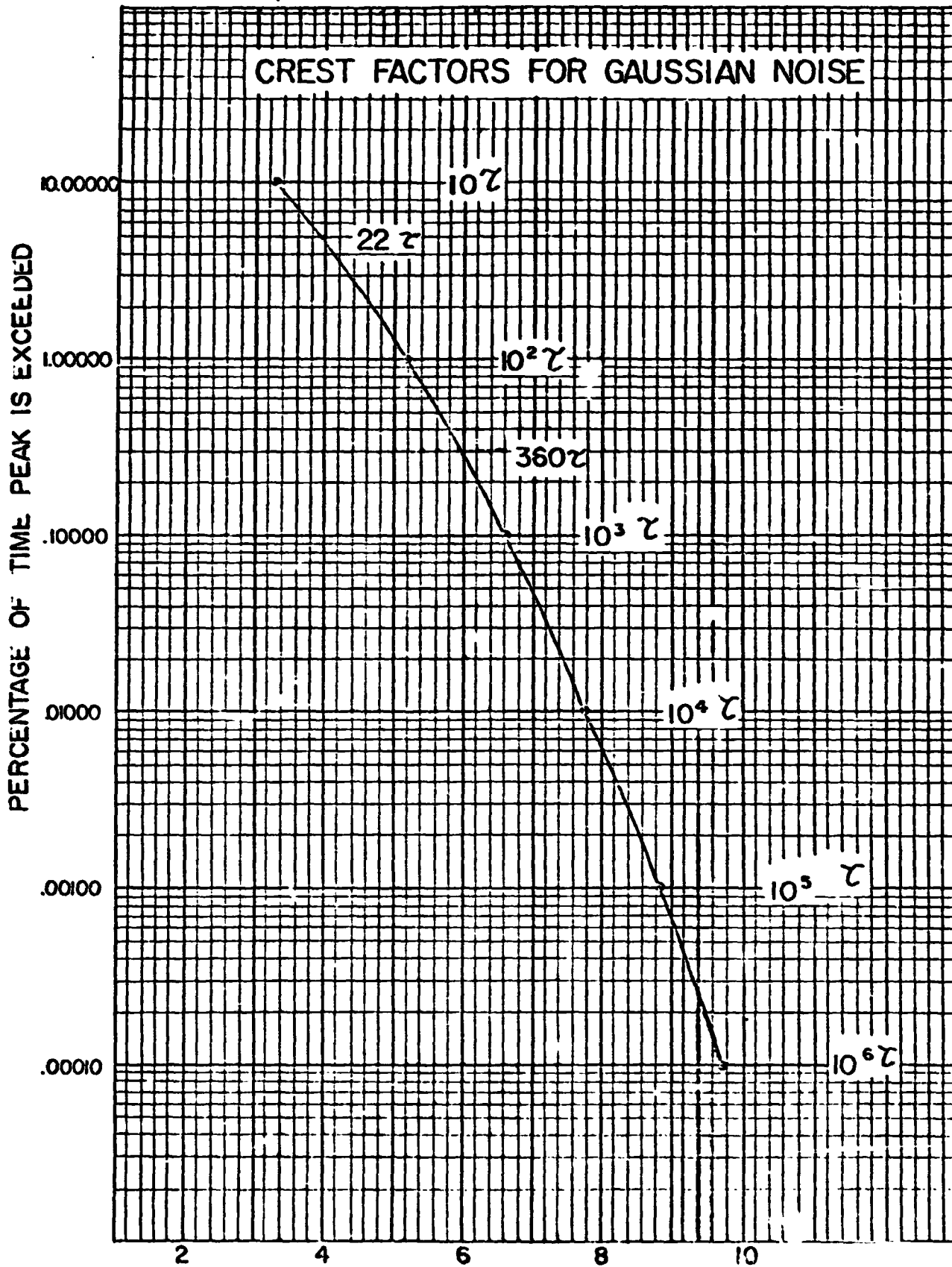
$$\text{Then preamp gain} = \frac{\text{Square wave p-p volts out}}{\text{Square wave p-p volts in}}$$

The gain of the PAR lock-in and chart recorder was obtained by fixing the PAR internal reference at the desired signal frequency and with a square wave of known amplitude, derived from a signal generator, at the signal input, sweeping the generator to obtain the beat frequency at the chart recorder output.

$$\text{Then PAR gain} = \frac{\text{Sine wave p-p volts out}}{\text{Sine wave p-p volts in}}$$

The noise bandwidth Δf was obtained from equation (5). Detector noise voltages thus obtained were compared with those obtained from the detector manufacturers as shown in Tables 4.4, 4.6, 4.10 and 4.12.

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$$\frac{V_{p-p}}{V_{rms}}$$

Ratio of peak-to-peak voltage and RMS voltage.

FIGURE 4.22

H-55

4.9 SYSTEM EFFICIENCY

System thruput or total optical and electronic efficiency was derived in a similar fashion as the noise voltages. Using the Eppley blackbody as the radiant source and with a known temperature at the reflective blackbody the coherent signal on each detector was displayed on the chart recorder as an average voltage output. System efficiency $\tau_o\tau_e$ was then obtained from equation 2. The d.c. signal response was related to the peak-to-peak square wave radiant input as shown in Figure 4.23 System gain was derived as in section 4.8.

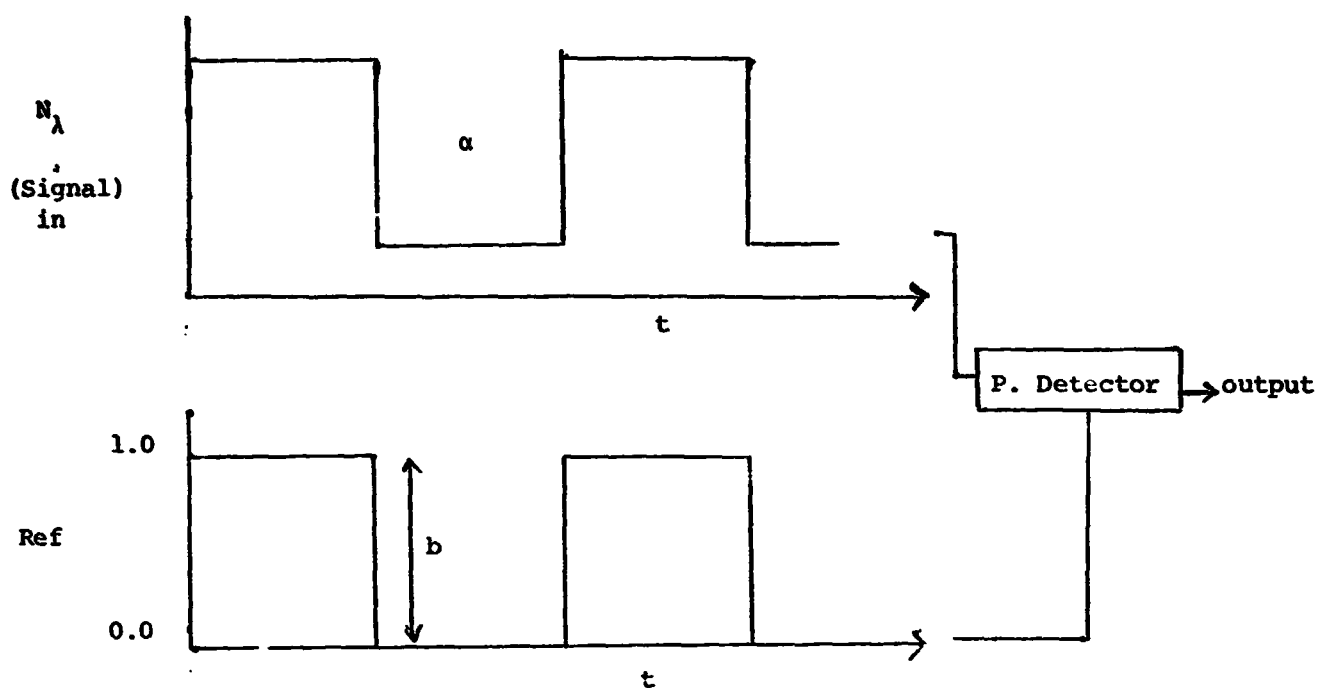
The differential ΔN_λ radiance was computed from the known temperatures of the source and reflective blackbody. Manufacturers data for responsivity and $\Delta\lambda$ were assumed and $A\Omega$ was calculated from design data. The magnitude of the response from each detector was obtained by consecutively allowing the radiant energy in each arm to be completely blocked, to obtain a baseline and then removing the blocker. Measured values for $\tau_o\tau_e$ were then compared with the predicted design data as shown in Tables 4.7 and 4.13.

Noise equivalent radiances (NEN) were then calculated from the noise voltage data using $\tau_o\tau_e$ as shown in equation (4). These NEN's were again compared with the design data as shown in Tables 4.7 and 4.13.

4.10 GAIN BALANCING

The gains of two of the preamps for both the PbSe and pyroelectric detectors were adjusted to give identical outputs to a fixed Eppley blackbody source. This was accomplished by using the outputs from two of the preamplifiers and coupling them via the PAR differential amplifier and lock-in amplifier to obtain zero output by adjusting the gain of the preamp with the largest signal at its output through a potentiometer located on the preamplifier. The output from the third preamplifier was then coupled with one of the first two outputs through the differential amplifier and lock-in amplifier and the gain of the third preamplifier adjusted to again obtain zero output. In each instance the differential output $V_1 - V_2$ and $V_1 - V_3$ were recorded and the noise voltages after being differentially coupled.

Fig. 4.23



$$\begin{aligned}
 \text{output} &= \int_T a \sin \omega t \cdot b \sin \omega t \, dt \\
 &= \int_T \left(\frac{1}{2} ab \cos 2\omega t - \frac{1}{2} ab \cos (\omega - \omega)t \right) dt \\
 &= - \int_T \frac{1}{2} ab \, dt + \int_T \frac{1}{2} ab \cos 2\omega t \, dt
 \end{aligned}$$

after filtering (integration)

$$= - \frac{1}{2} a b$$

4.11 ΔV GAS SIGNAL

Initially it had been intended to monitor the differential output from arms 1 and 2 to evaluate $V_1 - V_2$ as a function of gas signal input for the PbSe detectors. This required the use of the G.S.U. target source and absorption cell. Unfortunately due to scheduling problems only the target source was available and thus it was not possible to perform preliminary gas response tests. However it was found possible to place a 1 Cm x 1 1/2 inch diameter cell with sapphire windows containing 60 TORR CO backfilled with N_2 to a total pressure of 760 TORR. between the objective lens and the chopper disc and record the response. This test verifies that the brassboard was in fact capable of seeing 2×10^{-3} atm. cms. CO with a target source temperature of 33.4° C with an S/N (RMS) =1.

COMPARISON OF DETECTOR MANUFACTURER'S DATA & MEASURED DATA

Tables 4.4, 4.5, 4.6, 4.10, 4.11 and 4.12 give a comparison of the detector manufacturer's noise voltage data with that obtained on the brassboard, measured as outlined in section 4.8 for both PbSe and pyroelectric detectors.

Measured values for noise voltages were obtained under the following set of conditions in each case referred to the detector.

$$\text{Detector noise voltage} = (\text{Output p-p noise}) \times \frac{1}{\text{Crest factor}} \times \frac{1}{\text{Gain}} \times \Delta f^{-1/2}$$

($V_{\text{RMS}} \text{ Hz}^{-1/2}$)

Crest Factor = 5.2

Noise bandwidth = 0.25 Hz

Output p-p noise was obtained from the chart record.

V_{AV} was also obtained from chart record

NEN CALCULATIONS

NEN values were calculated for each arm of the brassboard at 4.6 microns and 11.2 microns as described in section 4.9. These values along with optical efficiency and throughput values were then compared with design values in Tables 4.7 & 4.13.

PYROELECTRIC DETECTORS

		12117	12142	12243
ROOM TEMP.	Area (cm)	.0404	.0402	.0402
	Responsivity (V/W)	725	762	725
	D* (cm Hz ^{1/2} W ⁻¹)	7.7 x 10 ⁸	9.5 x 10 ⁸	5.9 x 10 ⁸
	NEP (W)	2.56 x 10 ⁻¹⁰	2.087 x 10 ⁻¹⁰	3.38 x 10 ⁻¹⁰
7°C	Responsivity	627	725	650
	D*	4.7 x 10 ⁸	6.9 x 10 ⁸	3.9 x 10 ⁸

Table 4.2

Detector performance data supplied by manufacturer

ARM DETECTOR	3 No. 12117	2 No. 12142	1 No. 12243
Black Body Temps ($^{\circ}\text{C}$)	25.5	25.1	26.8
" " Radiance ($\text{WCm}^{-2}\text{Sr}^{-1}\mu^{-1}$)	9.44×10^{-4}	9.385×10^{-4}	9.25×10^{-4}
Source Temps ($^{\circ}\text{C}$)	30.45	30.34	30.74
" Radiance ($\text{WCm}^{-2}\text{Sr}^{-1}\mu^{-1}$)	1.015×10^{-3}	1.013×10^{-3}	1.019×10^{-3}
Δ Radiance ($\text{WCm}^{-2}\text{Sr}^{-1}\mu^{-1}$)	7.09×10^{-5}	7.45×10^{-5}	5.65×10^{-5}
P.A.R. GAIN	39.5	43.45	43.45
Noise Bandwidth (Hz)	.25	.25	.25
Pre-amp gain	3×10^3	1.92×10^3	2.38×10^3
V_{AV} Signal (V)	3.15	7.8	5.6
$V_{\text{p-p}}$ Noise (V)	90×10^{-3}	37.5×10^{-3}	90×10^{-3}
Crest Factor	5.2	5.2	5.2
Noise Voltage ($V_{\text{rms}} \text{Hz}^{-1/2}$)	2.65×10^{-7}	1.72×10^{-7}	3.34×10^{-7}
$\tau_o \tau_e$.045	.073	.058
N.E.P. (W)	3.66×10^{-10}	2.25×10^{-10}	4.6×10^{-8}
$D^* \text{ Cm Hz W}^{-1}$	5.46×10^8	8.89×10^8	4.34×10^8
NEN ($\text{WCm}^{-2}\text{Sr}^{-1}$)	8.19×10^{-7}	3.18×10^{-8}	8.19×10^{-8}

Table No. 4.3

Pyroelectric detector measured data

PYRO NO. 12117

	MANUFACTURER'S DATA	MEASURED DATA
D* Cm Hz ^{1/2} W ⁻¹	7.7 x 10 ⁸	5.46 x 10 ⁸
NOISE VOLTAGE (Vrms Hz ^{-1/2})	1.86 x 10 ⁻⁷	2.65 x 10 ⁻⁷

Table 4.4

Comparison of manufacturer's and measured data

PYRO NO. 12443

	MANUFACTURER'S DATA	MEASURED DATA
D* (Cm Hz ^{1/2} W ⁻¹)	5.9 x 10 ⁸	4.34 x 10 ⁸
NOISE VOLTAGE (Vrms Hz ^{-1/2})	2.45 x 10 ⁻⁷	3.34 x 10 ⁻⁷

Table 4.5

Comparison of manufacturer's and measured data

PYRO NO. 12142

	MANUFACTURER'S DATA	MEASURED DATA
D* (Cm Hz ^{1/2} W ⁻¹)	9.5 x 10 ⁸	8.89 x 10 ⁸
NOISE VOLTAGE Vrms Hz ^{-1/2}	1.59 x 10 ⁻⁷	1.72 x 10 ⁻⁷

Table 4.6

Comparison of manufacturer's and measured data

COMPARISON OF DESIGN & MEASURED BRASSBOARD

PERFORMANCE [NH₃]

		DESIGN (D)	MEASURED (M)
A_{Ω} (Cm ² Sr)		3.88×10^{-2}	4.85×10^{-2}
	Δf (Hz)	0.1	0.25
D^* (Cm Hz ^{1/2} W ⁻¹)	No. 1	5×10^8	4.34×10^8
	No. 2	5×10^8	8.89×10^8
	No. 3	5×10^8	5.46×10^8
$\tau_o \tau_e$	No. 1	.062	.058
	No. 2	.056	.073
	No. 3	.091	.045
NEN (WCm ⁻² Sr ⁻¹)	No. 1	5.26×10^{-8}	8.19×10^{-8}
	No. 2	5.82×10^{-8}	3.18×10^{-8}
	No. 3	3.58×10^{-8}	8.39×10^{-8}

Table No. 4.7

PbSe DETECTORS
(195°K performance)

	Detector 004	Detector 005	Detector 006
Area (Cm ²)	.04	.04	.04
Responsivity (V/W)	2.04×10^4	3.49×10^4	3.21×10^4
D* (4.7y, 172 Hz) (CmHz ^{1/2} W ⁻¹)	1.05×10^{10}	9.59×10^9	1.25×10^{10}

TEMP	185°K	180°K	192°K
Responsivity (V/W)	1.91×10^4	3.15×10^4	2.71×10^4
D*	1.08×10^{10}	1.39×10^{10}	1.48×10^{10}
197°K			
R.	2.85×10^4		
D*	1.29×10^{10}		

Table No. 4.8

PbSe detector performance data supplied by Opto Electronics.

ARM	1	2	3
Detector	No. 005	No. 004	No. 006
Black Body Temps ($^{\circ}\text{C}$)	25.	26.5	26.65
" " Radiance ($\text{WCm}^{-2}\text{Sr}^{-1}\mu^{-1}$)	1.807×10^{-4}	1.839×10^{-4}	1.848×10^{-4}
Source Temps ($^{\circ}\text{C}$)	30.57	30.65	30.68
" Radiance ($\text{WCm}^{-2}\text{Sr}^{-1}\mu^{-1}$)	2.11×10	2.116×10^{-4}	2.118×10^{-4}
Δ Radiance ($\text{WCm}^{-2}\text{Sr}^{-1}\mu^{-1}$)	3.03×10^{-5}	2.77×10^{-5}	2.7×10^{-5}
Detector Temps ($^{\circ}\text{K}$)	191	193	189
P.A.R. GAIN	43.5	39.55	43.5
Noise bandwidth (Hz)	.25	.25	.25
Pre-amp gain	473	773	555
Vav Signal (V)	3.35	2.05	2.3
Vp-p Noise (V)	46×10^{-3}	61×10^{-3}	35.3×10^{-3}
Crest Factor	5.2	5.2	5.2
Noise Voltage (Vrms $\text{Hz}^{-1/2}$)	8.6×10^{-7}	7.7×10^{-7}	5.6×10^{-7}
$\tau_o \tau_e$.101	.082	.084
N.E.P. (W)	2.46×10^{-11}	3.77×10^{-11}	1.77×10^{-11}
D^* ($\text{Cm Hz}^{1/2} \text{W}^{-1}$)	8.11×10^9	5.3×10^9	1.12×10^{10}
NEN ($\text{WCm}^{-2}\text{Sr}^{-1}$)	2.51×10^{-9}	4.71×10^{-9}	2.17×10^{-9}

Table No. 4.9

PbSe detector measured data

PbSe No. 005

	MANUFACTURER'S DATA	MEASURED DATA
D^* 4.7μ $(\text{Cm Hz}^{\frac{1}{2}} \text{ W}^{-1})$	9.59×10^9 at 195°K 1.387×10^{10} " 180°K	8.11×10^9 at 191°K
NOISE VOLTAGE $(\text{Vrms Hz}^{-\frac{1}{2}})$	7.27×10^{-7} at 195°K 4.54×10^{-7} " 180°K	8.6×10^{-7} at 191°K

Table 4.10

Comparison of manufacturer's and measured data

PbSe No. 004

	MANUFACTURER'S DATA	MEASURED DATA
D^* 4.7μ $(\text{Cm Hz}^{\frac{1}{2}} \text{W}^{-1})$	1.046×10^{10} at 195°K 9.99×10^9 " 195°K 1.077×10^{10} " 185°K 8.87×10^{10} " 195°K 1.29×10^{10} " 197.5°K	5.3×10^9 at 193°K
NOISE VOLTAGE $V_{\text{rms}} \text{ Hz}^{-\frac{1}{2}}$	3.9×10^{-7} at 195°K 4.0×10^{-7} " 195°K 3.55×10^{-7} " 185°K 4.57×10^{-7} " 195°K 4.4×10^{-7} " 197.5°K	7.7×10^{-7} at 193°K

Table 4.11

Comparison of manufacturer's and measured data

PbSe No. 006

	MANUFACTURER'S DATA	MEASURED DATA
D^* 4.7μ $(\text{Cm Hz}^{\frac{1}{2}} \text{ W}^{-1})$	1.25×10^{10} at 195°K 1.48×10^{10} " 182°K	1.12×10^{10} at 189°K
NOISE VOLTAGE $(\text{Vrms Hz}^{-\frac{1}{2}})$	5.13×10^{-7} at 195°K 3.66×10^{-7} " 182°K	5.6×10^{-7} at 189°K

Table 4.12

Comparison of manufacturer's and measured data

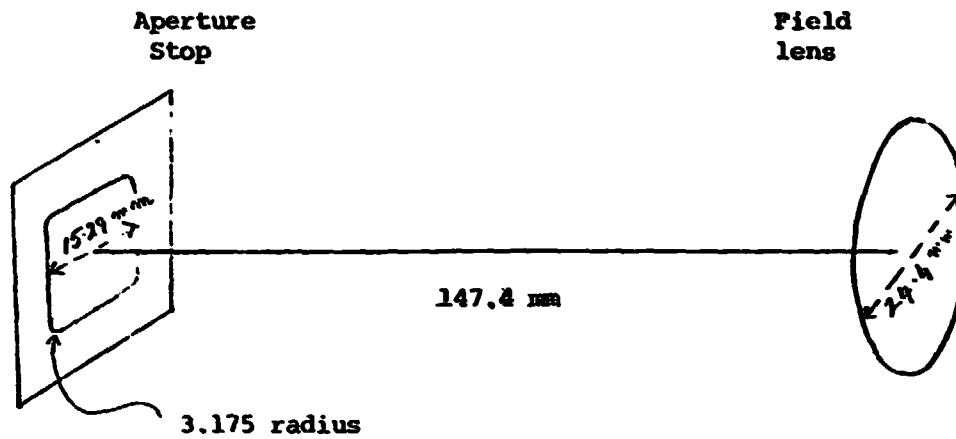
COMPARISON OF DESIGN & MEASURED BRASSBOARD

PERFORMANCE [CO]

	DESIGN (D)	MEASURED (M)
$A \Omega \text{ (Cm}^2 \text{Sr)}$	3.88×10^{-2}	4.85×10^{-2}
$\Delta f \text{ (Hz)}$	0.1	0.25
$D^* \text{ (Cm Hz}^{\frac{1}{2}} \text{W}^{-1})$ No. 1	1.2×10^{10}	8.11×10^9
No. 2	1.2×10^{10}	5.3×10^9
No. 3	1.2×10^{10}	1.12×10^9
$\tau_o \tau_c$ No. 1	.091	0.101
No. 2	.109	0.082
No. 3	.097	0.084
$NEN \text{ (WCm}^{-2} \text{Sr}^{-1})$ No. 1	1.49×10^{-9}	2.51×10^{-9}
No. 2	1.25×10^{-9}	4.71×10^{-9}
No. 3	1.40×10^{-9}	2.17×10^{-9}

Table 4.13

A Ω CALCULATION



$$A\Omega = \frac{A_{AS} \cdot A_{FL}}{d^2}$$

$$A_{AS} = (15.29)^2 - \left((3.125 \times 2)^2 - \pi (3.125)^2 \right)$$

$$= 225.4 \text{ mm}^2$$

$$A_{FL} = \left[\pi \frac{(24.4)^2}{4} \right]$$

$$= 467.6 \text{ mm}^2$$

$$A\Omega = \frac{225.4 \times 467.6}{(147.4)^2}$$

$$= \underline{\underline{0.0485 \text{ cm}^2 \text{ sr}}}$$

APPENDIX I

MAPS GAS CELLS CHEMICAL COMPATIBILITY LIFE TEST



INTEROFFICE CORRESPONDENCE

TO P. Hutchings

E. A. Burns
cc: C. Flegal
W. Massey
L. Peterson
R. Jones

4341.AC.76-118

DATE: 6-9-76

SUBJECT MAPS Gas Cells
Chemical Compatibility
Life Test

FROM: L.E. Ryan *L.E. Ryan*
BLDG MAIL STA. EXT.
01 2030 62451

- Reference 1: 4341.AC.75-165, Chemical Compatibility Study of MAPS Gas Cell, To: W. Massey, From: L.E. Ryan, 7-24-75
- Reference 2: Monitoring of Air Pollution by Satellites (MAPS) Phase 1 Report, Science Applications Incorporated.
- Reference 3: 4341.AC.76-062, Report on MAPS Gas Cell Filling and Recommendations for Future Modifications to Fill Station, To: P. Hutchings, From: L.E. Ryan, 3-19-76

Introduction

The design objective of the MAPS gas cell effort was to produce a chemically stable gas reference cell for the operational lifetime of the instrument. Chemical changes were of primary concern because reactions which would deplete the reference gases or introduce absorptive species into the band pass would effect instrument response. Theoretically the cell design maintains an interior which is inert to the carbon monoxide, and ammonia fill gases. However, a life test was conducted to verify that the stability of these cells met the design criteria of a maximum 1% signal change over a two year period.

Test Sequence

Initially the windows used for these life test MAPS cells were characterized by an optical microscopic inspection. This inspection was conducted to look for any flaws. These windows were also scanned in the infrared (2.5-15 microns). These preparation tests were conducted to provide a baseline reference for each window in the event a life test

failure indicated that the window materials were involved.

The cells for life test were processed and filled according to established MAPS procedures, reference 3. They were then leak checked to verify vacuum integrity, infrared scanned, and exposed to 85°C for 400 hours to simulate 3 years of life at 25°C (Determined from Arrhenius Equations - Influence of Temperature on the Rate of Reaction). After this exposure infrared scans were conducted to verify that changes had not taken place. Life test cell S/N 112, 5% NH₃ was cross sectioned in half at the end of these tests and the windows were reexamined and window #3 rescanned in the infrared.

The life test cells are identified below:

Table I: Life test Cell Assignments

Cell S/N	Fill Gas	Windows
108	35% CO	288517B, #3 and #4
110	10% CO	288517B, #8 and #9
109	20% NH ₃	288517A, #5 and #6
112	5% NH ₃	288517A, #3 and #4

Life Test Data

1. Window Characterization

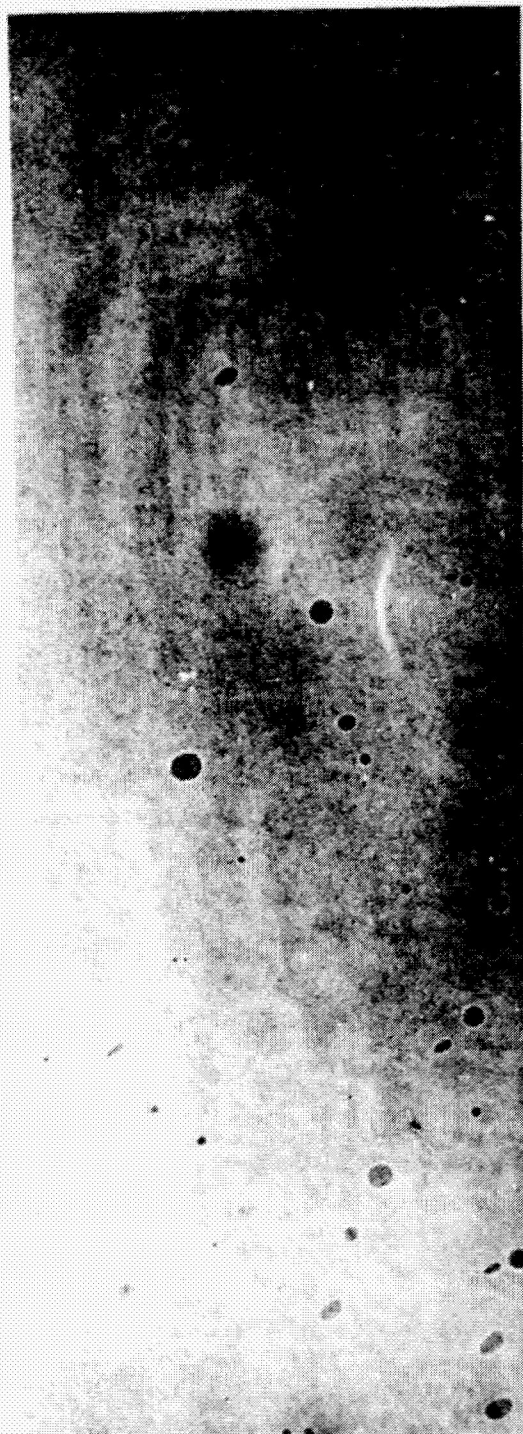
The sapphire windows appeared to be free of defects. Cell S/N 108 had been constructed with windows #3 and #4 and Cell S/N 110 with windows #8 and #9.

The germanium windows were free of defects in appearance on the uncoated side. The antireflectance coating, however, was uneven on all the windows inspected. It appeared to be spotted with noncoated areas present (Window numbers #2, #3, #4, #5, #6 and #7)*. Photograph #1 shows a 500X magnification of window #3 which was used on life test cell S/N112.

*Windows #2 and #7 were used on retrofit cell S/N114.

Photograph 1: Window
#3, germanium, two
areas at 500X of anti-
reflectance coating
defects, used on S/N112.

4341.AC.76-118
6-9-76



Area #1

Spotted Area



Area #2

Noncoated
Area

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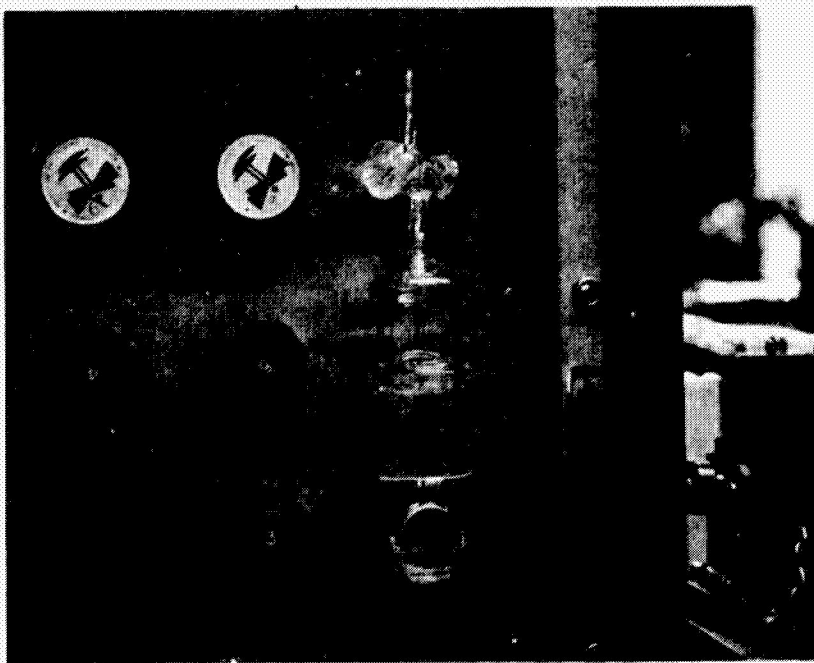
Cell S/N 112 had been constructed with windows #3 and #4 and life test cell S/N 109 with #5 and #6.

The windows from S/N 112 were carefully inspected after the life test and changes were not detected on the surface in contact with the NH_3 .

Infrared transmittance scans were conducted on all these windows before cell construction. The initial scan of the germanium #3, S/N 112 cell, window is attached, scan #1. This same window was rescanned after cross sectioning and is also attached, scan #2. The transmittance characteristics were unaffected by contact with the NH_3 .

2. Vacuum Integrity

These cells were scanned in the infrared just prior to vacuum exposure, scans #3, 4, 5, and 6. The vacuum exposure was conducted in a bell jar attached to the inlet system of a Hitachi/Perkin Elmer Mass Spectrometer, RMU-6, Photograph 2.



Photograph 2
MAPS
gas cell
S/N 109 during
Vacuum
Integrity
Analysis

After the bell jar was evacuated to approximately 5×10^{-8} torr., the bell jar was valved-off from the rest of the system. The cell, with approximately 1 atm. of fill gas, was then allowed to equilibrate with the vacuum environment of the bell jar for one hour. (If a leak were present the fill gas would tend to escape into the bell jar). Upon reventing into the mass spectrometer the increase in pressure was recorded and a mass scan was conducted of the contents of the bell jar. The data from these tests are recorded below:

Table II: Vacuum Exposure Mass Spectrophotometer Data

Sample/Cell	Mass Scan Data
Standard Helium leak, 8.8×10^{-10} attached to bell jar vent.	Helium detected strongly after one hour, a 5 unit peak height at lowest sensitivity. A trace of air also present. 5.8×10^{-8} torr. final pressure.
Background of bell jar, no cell present.	Air detected along with outgassing of silicone grease used on ground glass joint and vent valve. 8.0×10^{-8} torr. final pressure.
S/N 108 S/N 109 S/N 110 S/N 112	Same as background materials. Neon was not detected. Change in pressure less than change in helium standard leak.

Leaks were not detected in any of these cells. They were again scanned in the infrared and these scans were compared with those conducted before the vacuum exposure, scans #7,8,9, and 10. The intensities of the absorptions peaks had not changed indicating again that no loss of gas had taken place during vacuum exposure. It should be noted that differences in these scans and those just after filling and tip-off are due to instrumental differences in the spectrophotometers. The Beckman I.R. 20A was the only instrument available at the time the vacuum exposure tests were conducted.

Table III: Infrared Peak Intensities, Before and After Vacuum Exposure

Cell	Peak measurement in inches from base line, CO at 2150cm^{-1} and NH_3 at 970 cm^{-1} *	
	Before Exposure 3-18-76	After Exposure 3-22-76
S/N 108	0.875	0.900, Slight increase due to instrumental variations
S/N 109	1.63	1.75, Slight increase due to instrumental variations
S/N 110	0.49	0.49, No change
S/N 112	0.93	0.93, No change

3. Thermal Exposure

The thermal exposure was conducted in a quartz chamber, Photograph 3. This was designed to provide a constant purge of heated (85°C) dry nitrogen on the exterior of the cells and also provide handling protection for them during testing.



Photograph 3:
Thermal Exposure
Chamber, from left
to right.
S/N 112, S/N 110
S/N 109, and S/N
108

After 400 hours of exposure at 85°C the cells were removed from the test chamber and inspected under an optical microscope. The two shapphire windowed cells S/N 108 and S/N 110 provided a clear view of the gold plated cell walls, where discoloration that could be attributed to titanium diffusion could be observed if present. Discoloration was not observed up to 400X magnification. The germanium windows were carefully inspected for change in the antireflectance coating at the elevated temperature. Again changes were not observed.

Infrared scans on the cells were then conducted and compared with the post fill scans (approximately 2 months prior).

Table IV: Infrared Peak Intensities, Post Fill and Post Life Test

Cell	Peak measurement in transmittance units from base line, CO at 2150 cm^{-1} and NH_3 at 970 cm^{-1} *	
	Post Fill 2-13-76/2-20-76	Post Life Test 4-9-76
S/N 108	20, Ref. 3	21, scan #11
S/N 109	45, Ref. 3	45, scan #12
S/N 110	12, Ref. 3	12, scan #13
S/N 112	39, Ref. 3	0, scan #14

The only detectable change occurred in cell S/N 112, 5% NH_3 where the absorption peaks attributed to NH_3 were not detectable.

4. Failure Analysis of S/N 112

There were three possible mechanisms for NH_3 loss in S/N 112:

- 1) absorption of NH_3 on cell wall
- 2) escape of the fill gas, and
- 3) degradation to a nonabsorbing species.

To investigate NH_3 absorption on the cell wall. The NH_3 cell was placed in a cell holder in the optical path of the Perkin Elmer 521.

* Conducted on Perkin Elmer 521.

The outside circumference of the cell body was wrapped in heating tape and elevated to $110^{\circ}\text{C} \pm 10^{\circ}\text{C}$. This should have been sufficient to drive any absorbed NH_3 into the optical path. Scans were run after 1/2 hour, 3 hours and overnight. The scan after 3 hours is attached scan #15, and shows that NH_3 was not vaporized.

It had been verified by the vacuum integrity test that a leak was not present. However, the existence of stress in the cell with exposure to 85°C could have propagated a fracture in the pyrex. The cell was first very carefully reexamined using an optical microscope to verify that an observable defect was not present. The cell was found to be intact and the fill-tube stub was free of defects.

This cell was then placed in leak check bell jar, evacuated to 1×10^{-6} torr., back-filled with NH_3 gas to 1 1/2 atm., and placed in the 85°C oven for approximately 3 hrs. This was attempted to force the NH_3 back into the cell through any fissure that may have been present at the elevated temperature. When the apparatus was removed from the oven there was still a positive pressure of NH_3 . The cell was then rescanned, scan #16, and NH_3 was not found. (Note: I.R. scan shows that the exterior of the cell was contaminated with outgassing from the silicone grease). A similar exposure test was also conducted at the elevated temperature with the cell immersed in Freon 113. Again gas had not entered the cell. The general conclusions of these tests were that there was no leak present through which the gas escaped. However, a recommendation was made to conduct a hermeticity inspection based on an incoming component evaluation test procedure. The test chosen was a "radaflow" inspection test. This consisted of exposing the cell to radioactive Krypton in an automated testing apparatus, which evacuates, back-fills with Krypton, and then counts any Krypton leaking from the device being tested. At the completion of this test, the cell was found with the fill tube stub broken off. In fact, the fill tube stub was found outside of the beaker in which the cell had been placed, indicating that the cell received a substantial shock. The cell was, therefore, lost to testing of the last mechanism (gas degradation to a nonabsorbing species).

Ammonia theoretically can be decomposed at an elevated temperature to nitrogen and oxygen in the presences of a transition metal catalyst. Therefore, if nickel or titanium were in contact with the fill gas under the 85°C life test condition the 5% ammonia would become the infrared nonabsorbing species of nitrogen and oxygen. The presence of nickel in the interior of the cells had been noted in the past. Even though inspection procedures were established during this phase of cell manufacturing to eliminate this problem, the carbon monoxide cells S/N 101 and S/N 102 after 2 months of storage contained nickel tetracarbonyl absorptions, scans #17 and #18. Two steps were taken to verify that gas degradation had indeed taken place:

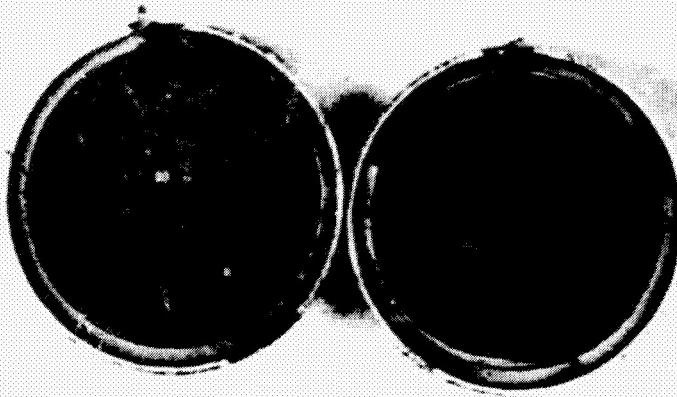
- 1) verification that at 85°C and with nickel present, the ammonia would decompose and
- 2) examination of cell S/N 112 for nickel.

The 5% ammonia fill gas was first analyzed using the mass spectrometer for impurities. It was free from contaminants. A nickel body, 5 cm, standard infrared gas cell was then fill, scanned (scan #19), placed in the 85°C exposure for 24 hours. This cell was then rescanned and the absorption spectrum for ammonia was not detected (scan #20). The gas was then vented into the mass spectrometer. Nitrogen, hydrogen and the neon tracer were detected. The cell was also heated to approximately 110°C, to verify that the ammonia had not absorbed on the cell walls, no change was detected in the mass spectroscopic data. This test was repeated at a 48 hour time period and the same results were obtained.

The cell was then cross sectioned by cutting through the cell body to allow for inspection of the window to body interface, Photograph 4. One window, #3, appeared to be completely sealed, an obvious ring of gold could be observed at the window/pyrex interface.

4341.AC.76-118
6-9-76

Photograph 4:
Cell S/N 112
Cross Sectioned



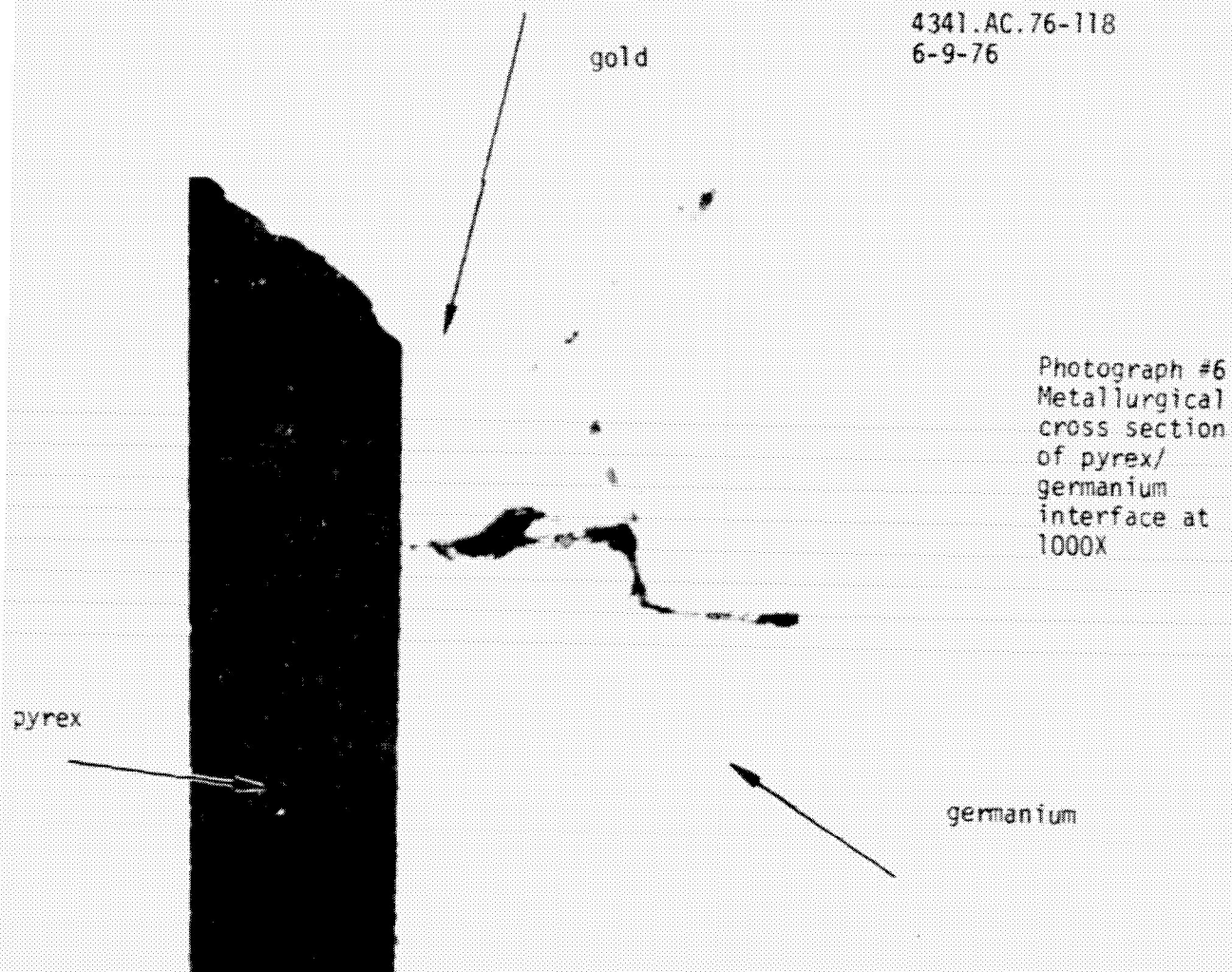
The other window, #4, appeared to have this gold seal missing from approximately one-half its circumference (the half opposite the fill tube aperture). Metallurgical examinations were made at four points on this section. Two showed there were unmetallized gaps between the pyrex/germanium interface, Photograph #5, and at two other points there was obviously gold, Photograph #6.



Photograph #5
Metallurgical
Cross Section
of Pyrex/
germanium
Interface at
1000X

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6-9-76




It appears that areas along this lower half did not become sealed by gold and contact with the catalytic nickel took place. However, it also appears to be a random occurrence and may be very difficult to inspect for or control during manufacturing.

Conclusions

The MAPS gas cell, as designed, is a chemically stable means of containment for the reference pollutant gases. Loss of signal in either NH_3 or CO cells can only occur when improper processing produces a pyrex/window interface contaminated with nickel.

4341.AC.76-118
6-9-76

Current scans, 6-9-76, of cells S/N 108, 190 and 110 are attached and show no detectable differences from those obtained after cell tip-off on 2-20-76.

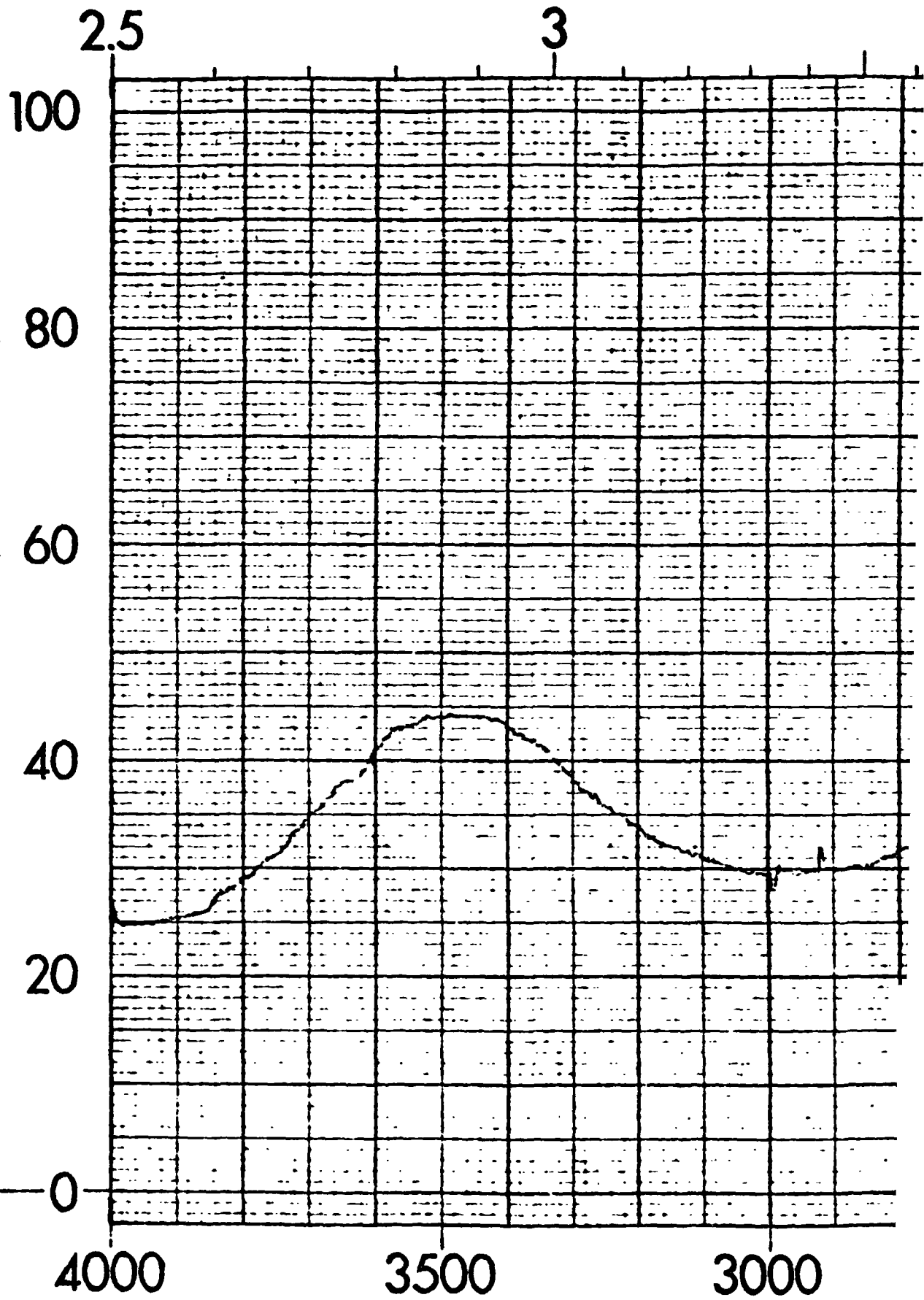
Approved: 
A. Grant, Section Head
Analytical Chemistry

Infrared Scans

1. Germanium window, S/N 288517A, #3 before cell manufacturing.
2. Germanium window, S/n 288517A, #3 after life test.
3. S/N 108, before vacuum integrity test.
4. S/N 109, before vacuum integrity test.
5. S/N 110, before vacuum integrity test.
6. S/N 112, before vacuum integrity test.
7. S/N 108, after vacuum integrity test.
8. S/N 108, after vacuum integrity test.
9. S/N 110, after vacuum integrity test.
10. S/N 112, after vacuum integrity test.
11. S/N 108, after life test.
12. S/N 109, after life test.
13. S/N 110, after life test.
14. S/N 112, after life test.
15. S/N 112, cell wall heated for 3 hours.
16. S/N 112, cell exposed to NH_3
17. S/N 101, after 2 months storage.
18. S/N 102, after 2 months storage.
19. 5 cm Test Cell, 5% NH_3 filled
20. 5 cm Test Cell, after 24 hours at 85°C
21. S/N 108, Scanned on 6-9-76
22. S/N 109, Scanned on 6-9-76
23. S/N 110, Scanned on 6-9-76

SAMPLE _____

TRANSMITTANCE (PERCENT)



FOLDOUT FRAME |

WAVELENGTH (MICRONS)

4

5

6

100

80

60

40

20

0

2500

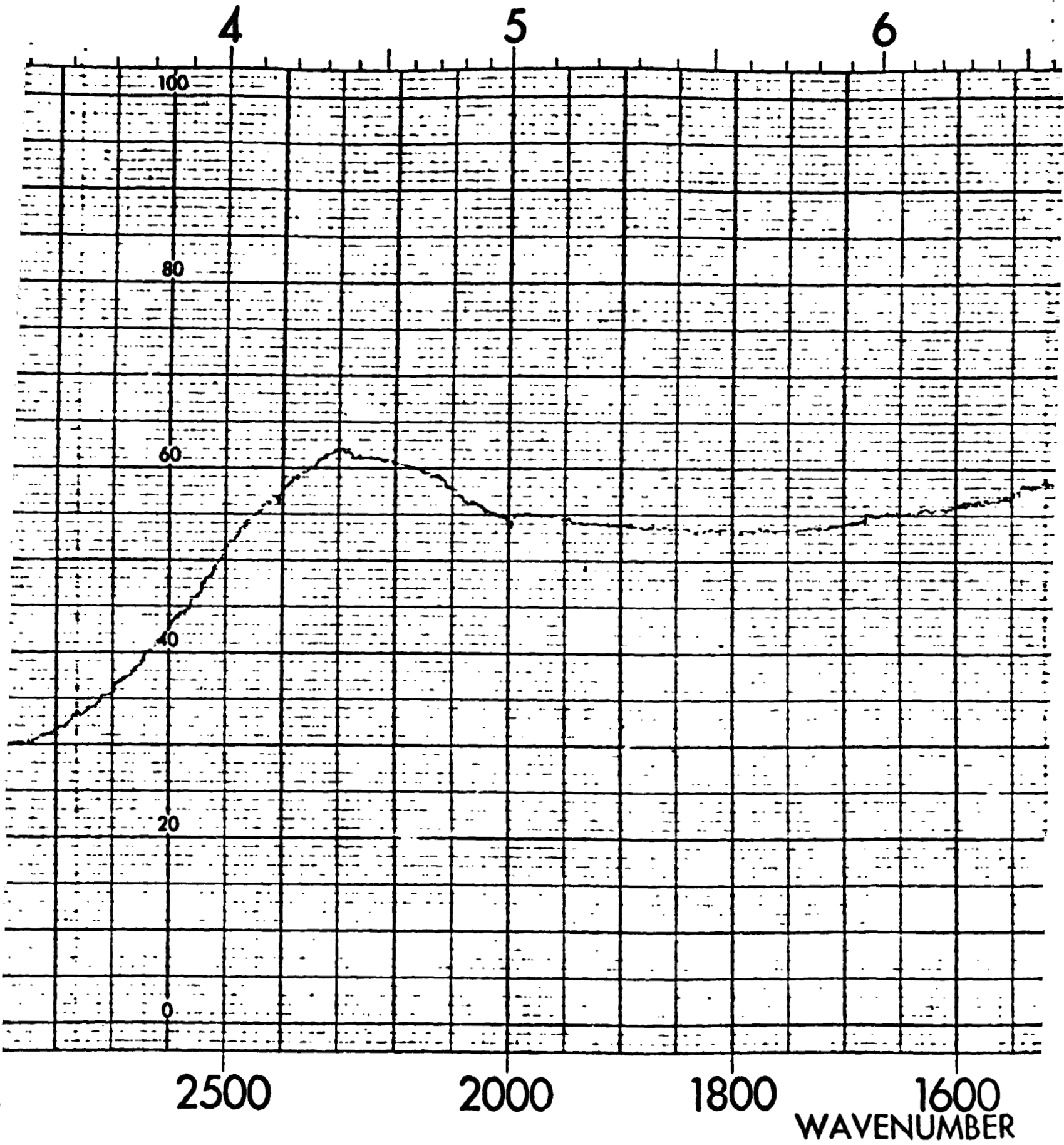
2000

1800

1600

WAVENUMBER

FOLDOUT FRAME 2



TRONS)

7

8

9

10

12

15

100

100

80

80

60

60

40

40

20

20

0

0

(CM⁻¹)

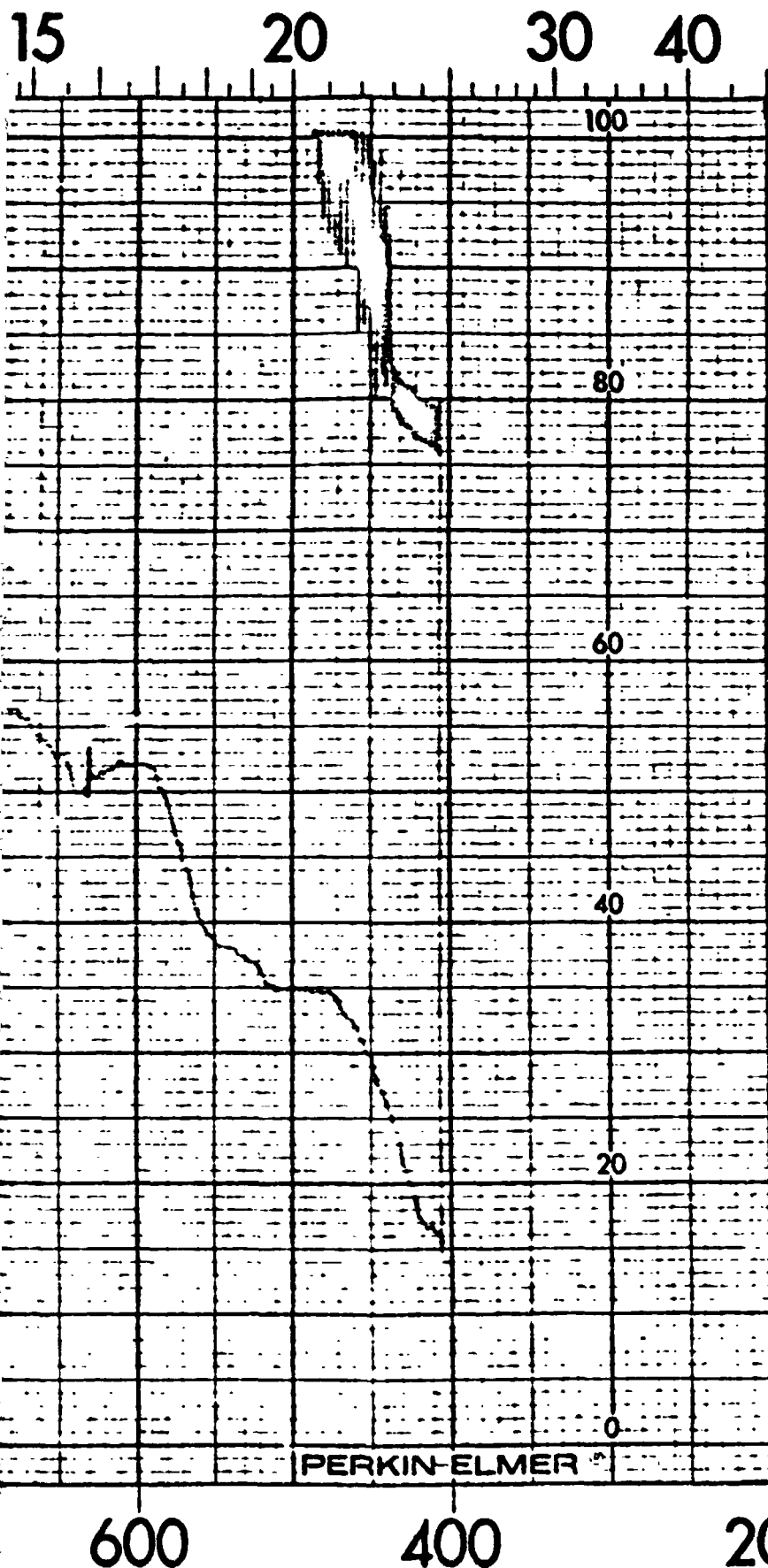
1400

1200

1000

800

OUT FRAME



SPECTRUM NO. B-02703
 SAMPLE X 288518A #3
1012 - 174

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 12/5/75

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

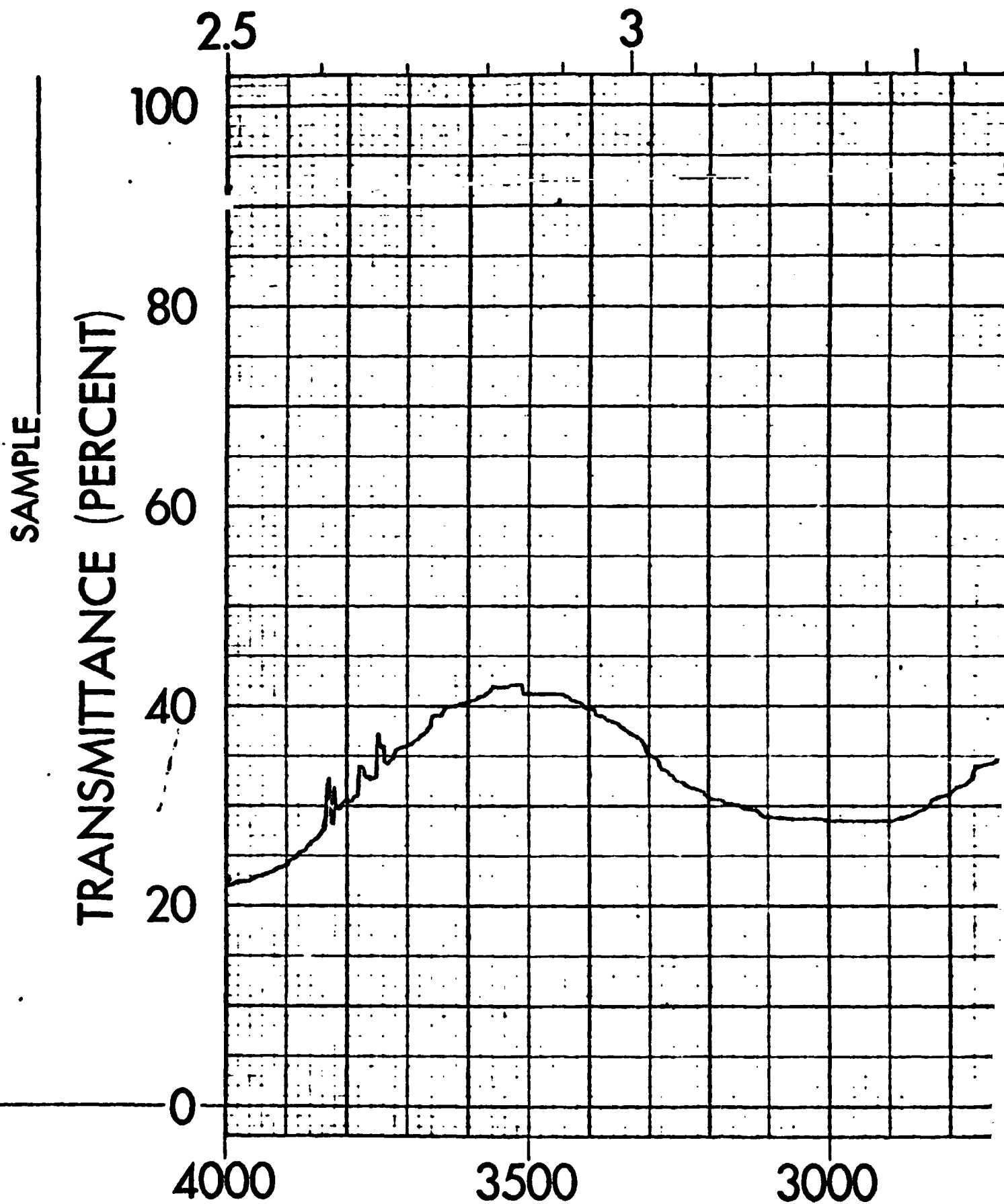
SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION _____

SOURCE CURRENT _____

NO. 221-1607



WAVELENGTH (MICRONS)

4

5

6

100

100

80

80

60

60

40

20

0

2500

2000

1800

1600

WAVENUMBER (CM⁻¹)

WAVENUMBERS (CM⁻¹)

7

8

9

10

12

15

100

100

80

80

60

60

40

40

20

20

0

0

1400

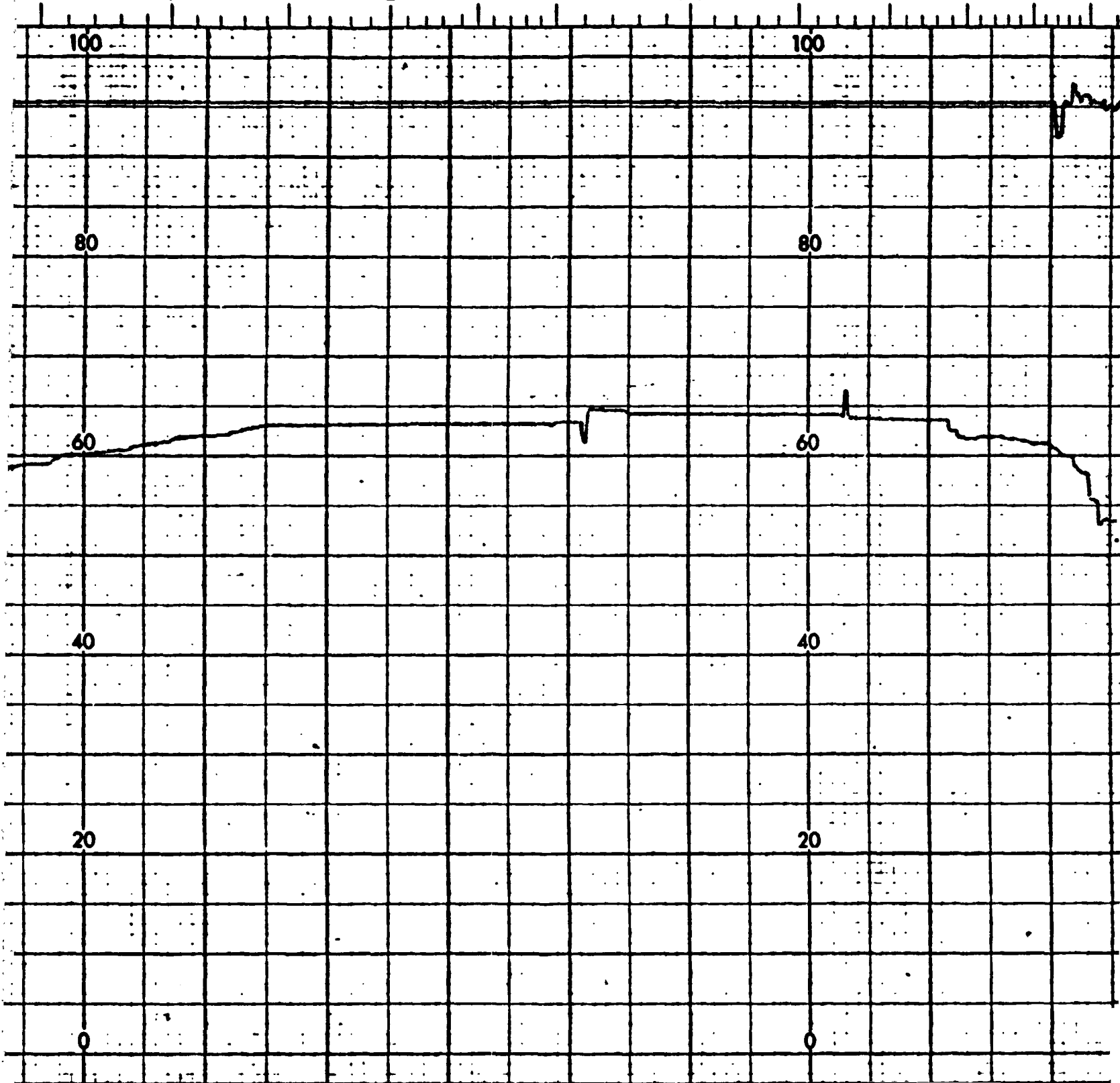
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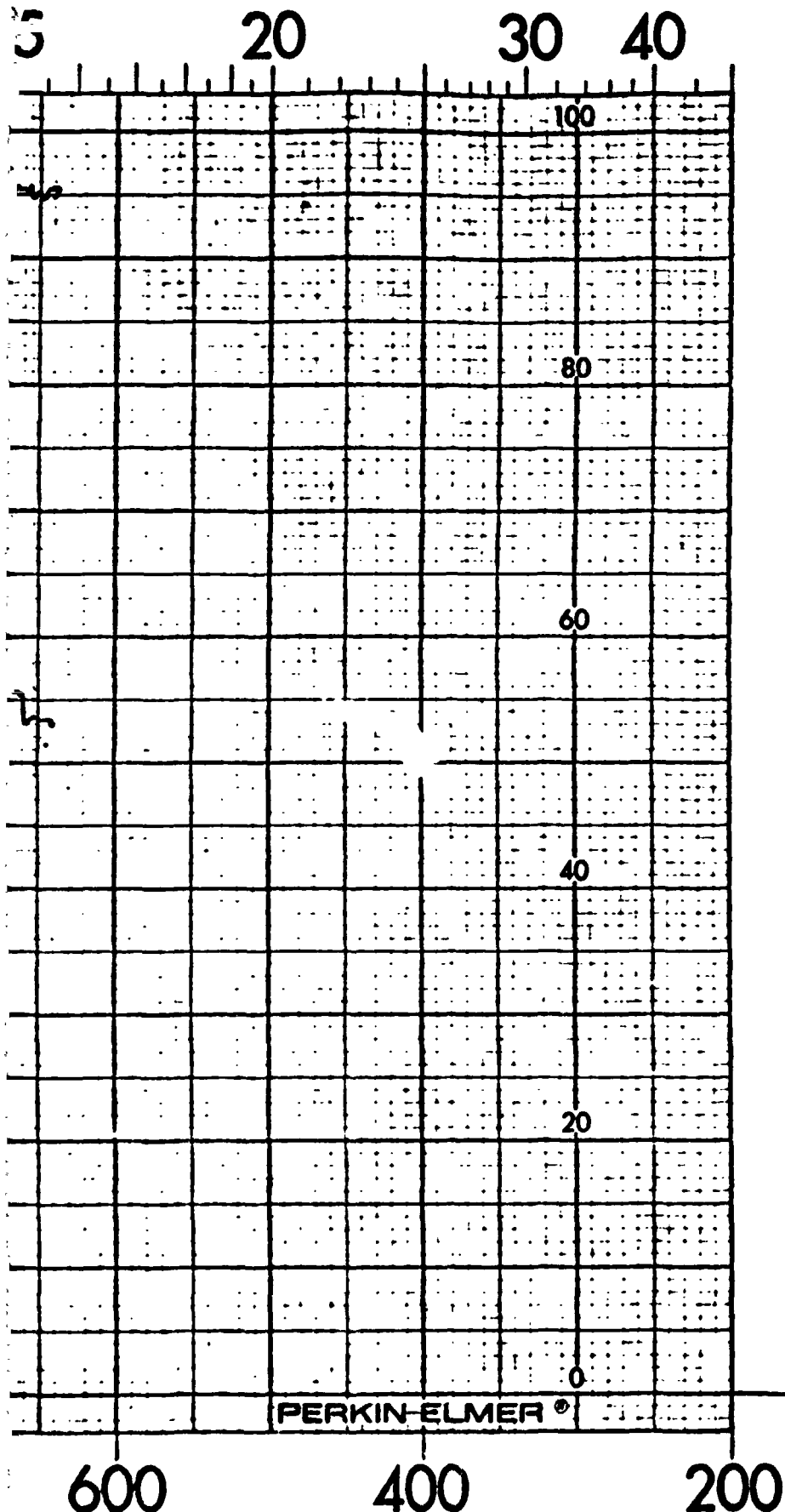
1000

800

W (CM⁻¹)

FOLD OUT FRAME →



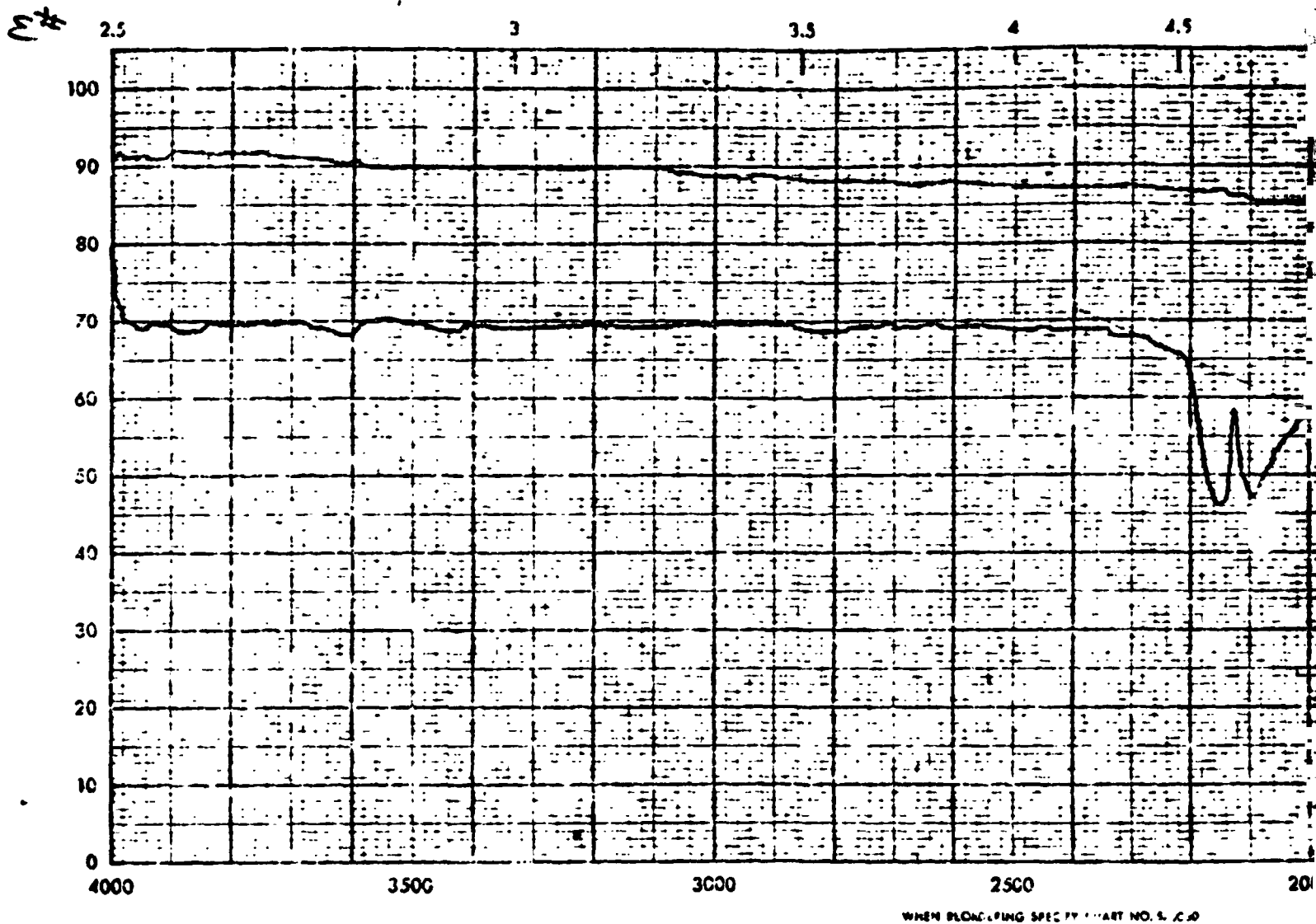


SPECTRUM NO. B-03266
SAMPLE GERMANIUM #3
GAS CELL S/N 112
ORIGIN _____
PURITY _____
PHASE _____
THICKNESS _____
1. _____
2. _____
3. _____
DATE 6/7/76
OPERATOR KENNEDY
REMARKS _____
MODEL 521 2:1 SCALE CHANGE _____
SLIT PROGRAM _____
GAIN _____
ATTENUATOR SPEED _____
SCAN TIME _____
SUPPRESSION _____
SCALE EXPANSION _____
SOURCE CURRENT _____

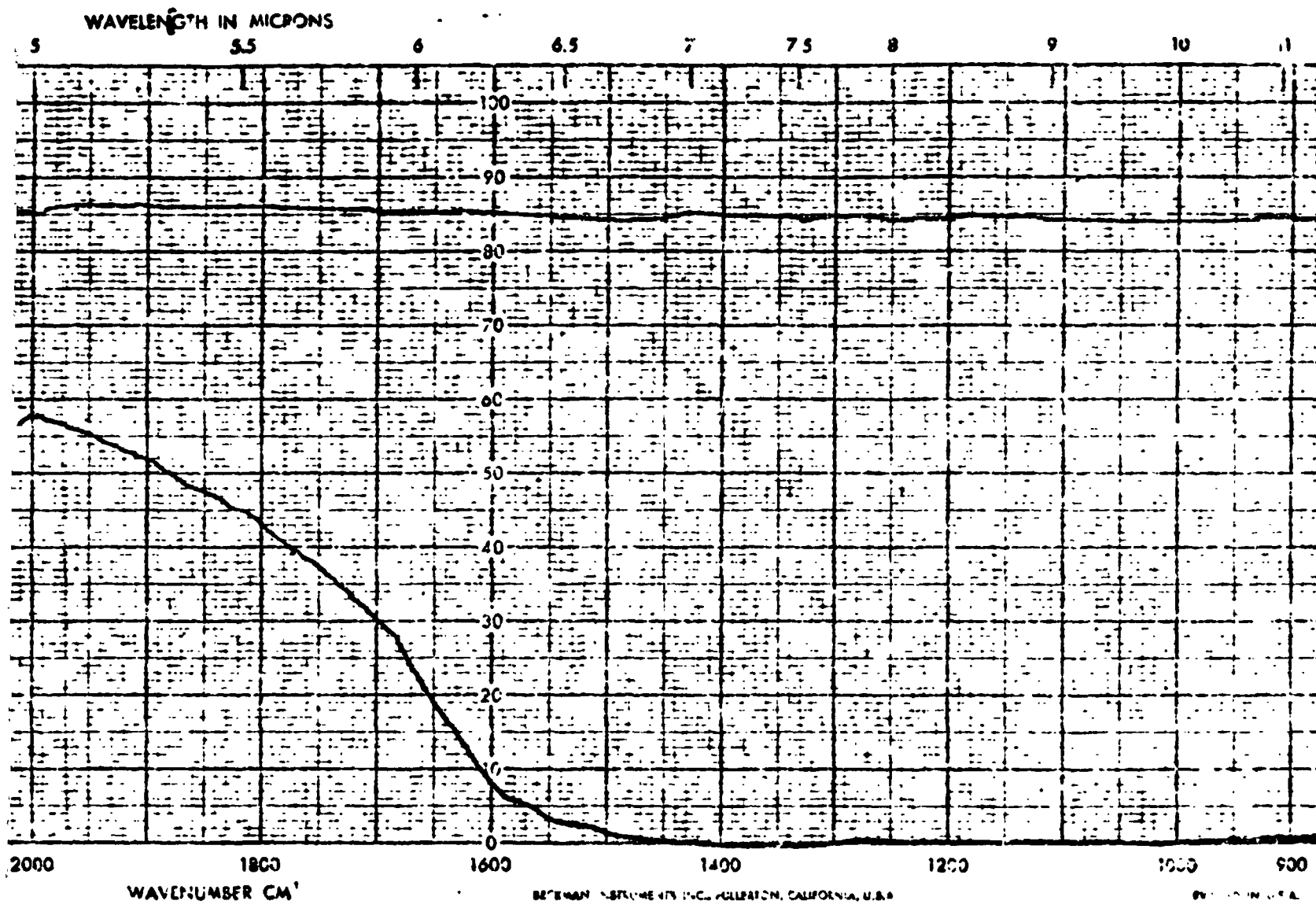
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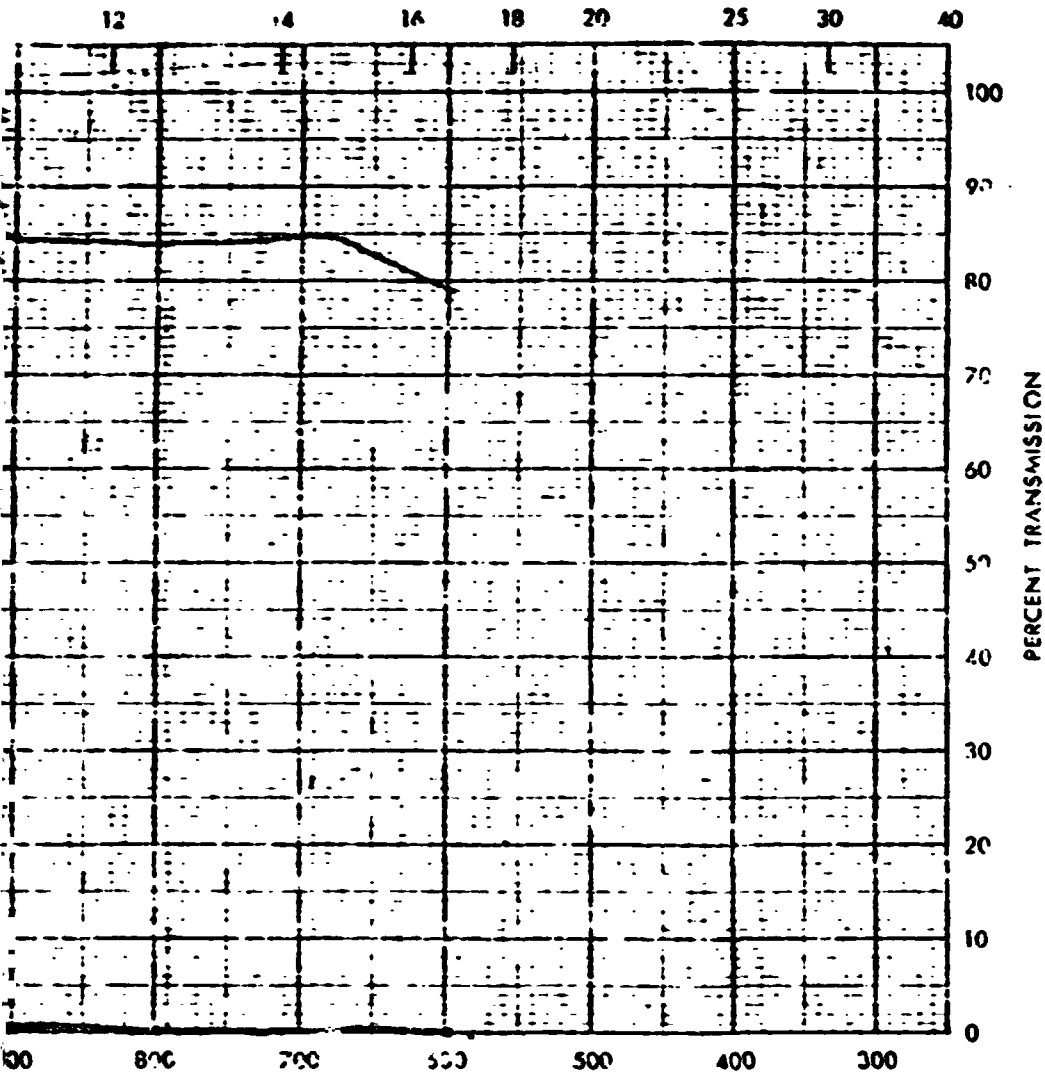
John Kennedy

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SPECTRUM NO. B-02971
DATE 3/18/76
SAMPLE GAS CELL 3/1108

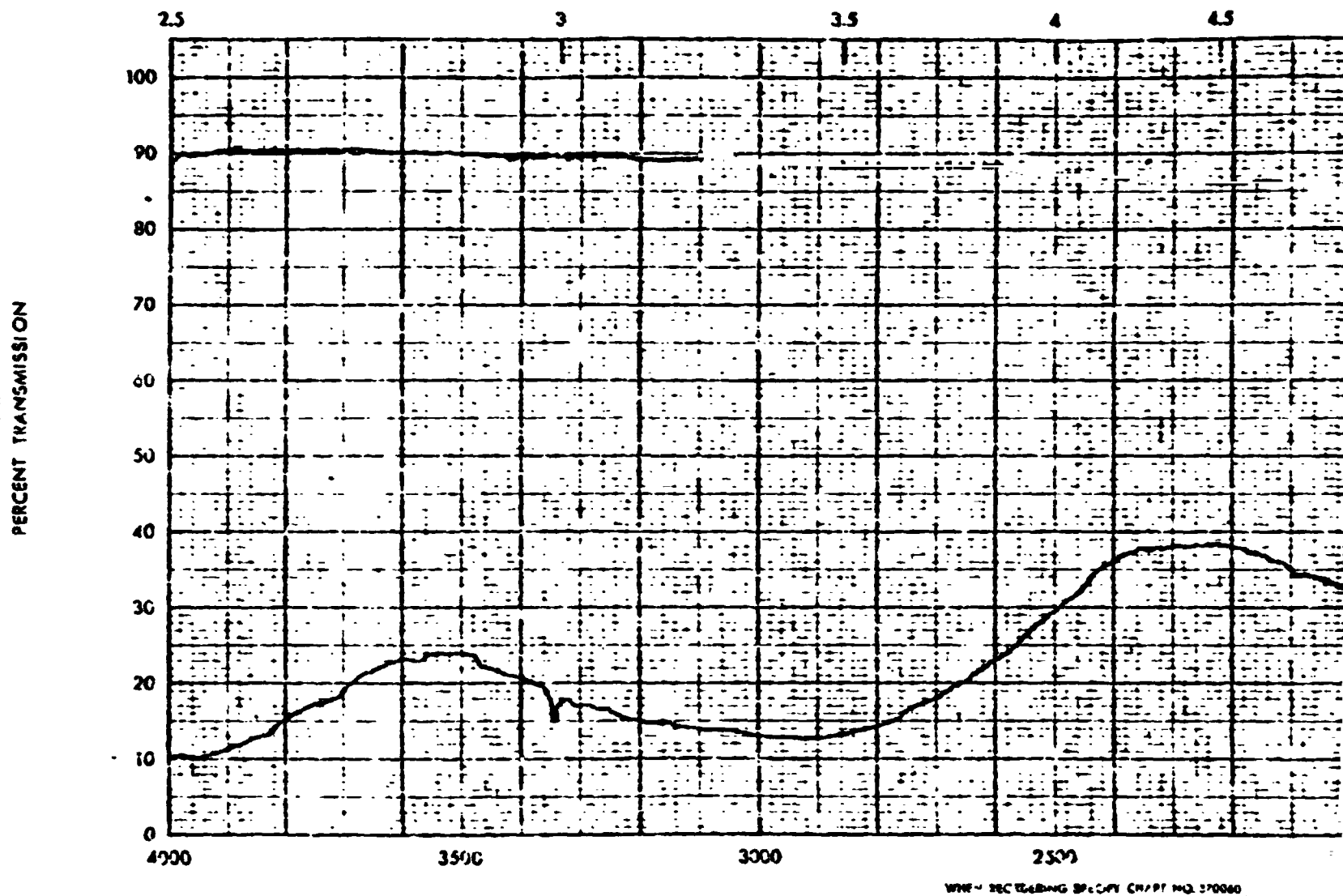
SOURCE _____
STRUCTURE _____

PATH _____ mm
SOLVENT _____
CONCENTRATION _____
PHASE _____
COMMENTS 1.5" x 2.5"

ANALYST KENNEDY

Beckman
INFRARED
SPECTROPHOTOMETER

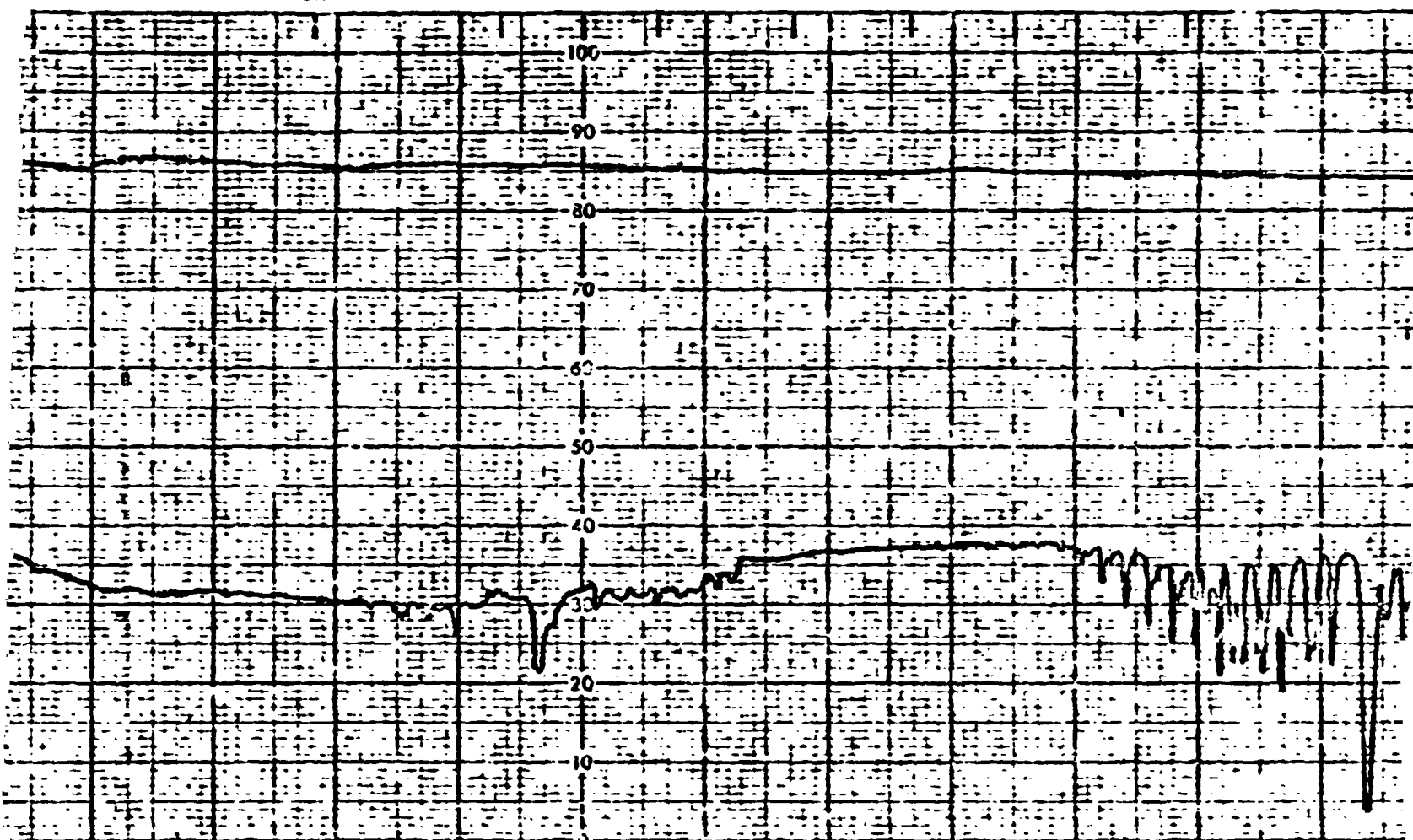
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WAVELENGTH IN MICRONS

5 5.5 6 6.5 7 7.5 8 9 10



2000

1800

1600

1400

1200

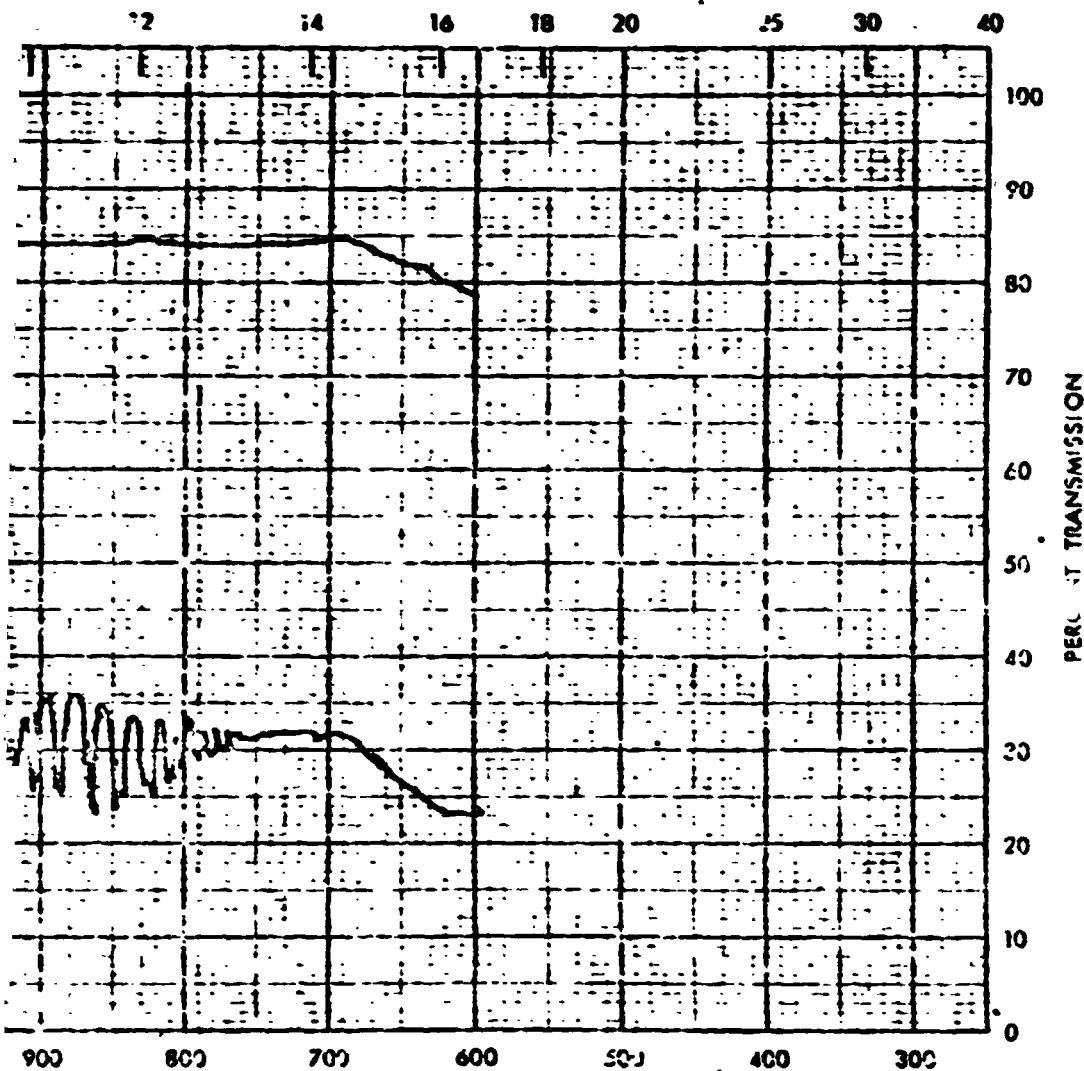
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WAVENUMBER CM⁻¹

"BECMAN INSTRUMENTS INC. FULLERTON, CALIFORNIA U.S.A."

1000000

512



SPECTRUM NO. B-02972

DATE 3/18/76

SAMPLE GAS CELL S/N 109

SOURCE _____

STRUCTURE _____

PATH _____ mm

SOLVENT _____

CONCENTRATION _____

PHASE _____

COMMENTS _____

1.12 x 10⁻³

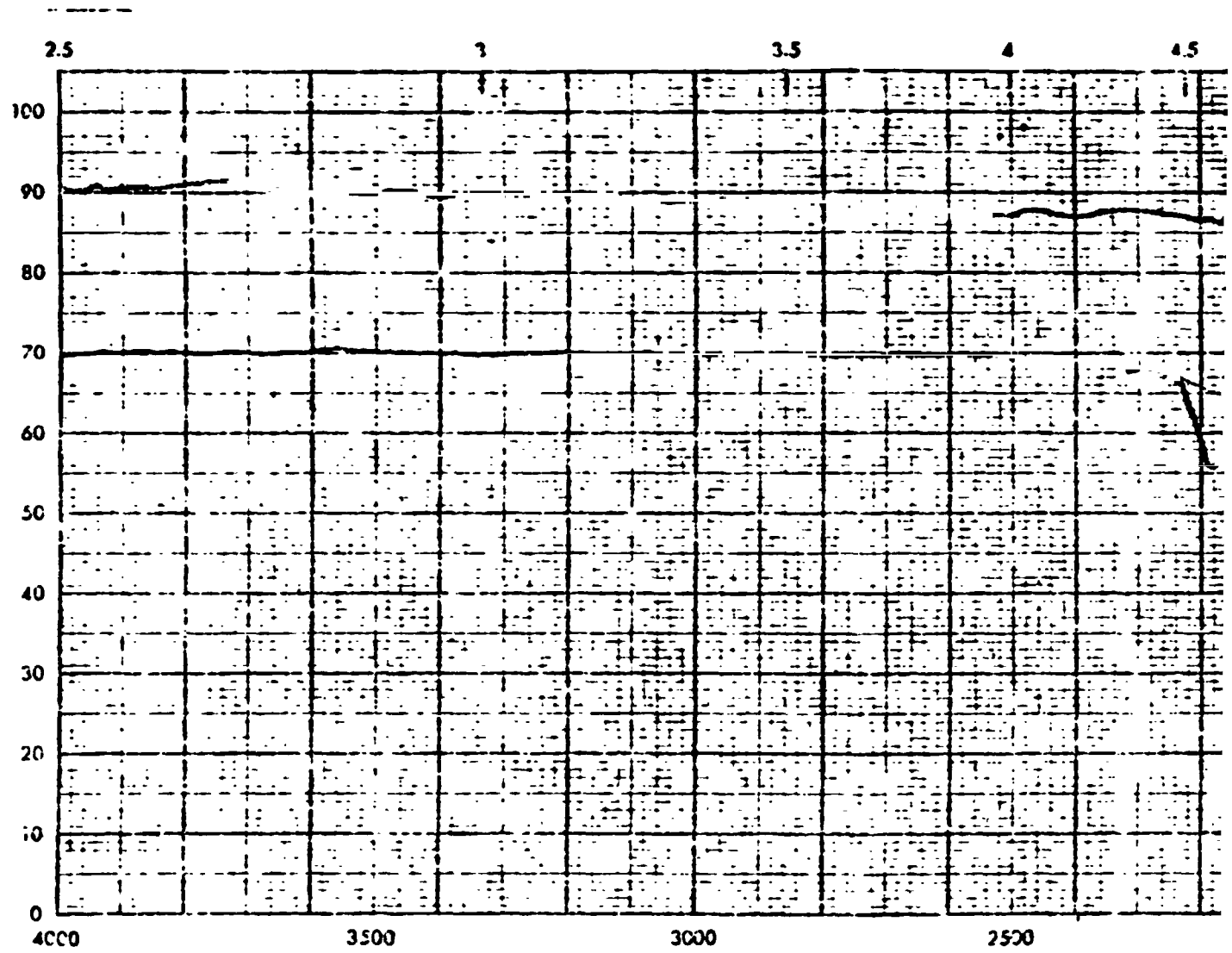
ANALYST KENNEDY

Beckman®

INFRARED
SPECTROPHOTOMETER

PERCENT TRANSMISSION

2#



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WAVELENGTH IN MICRONS

4.5

5

5.5

6

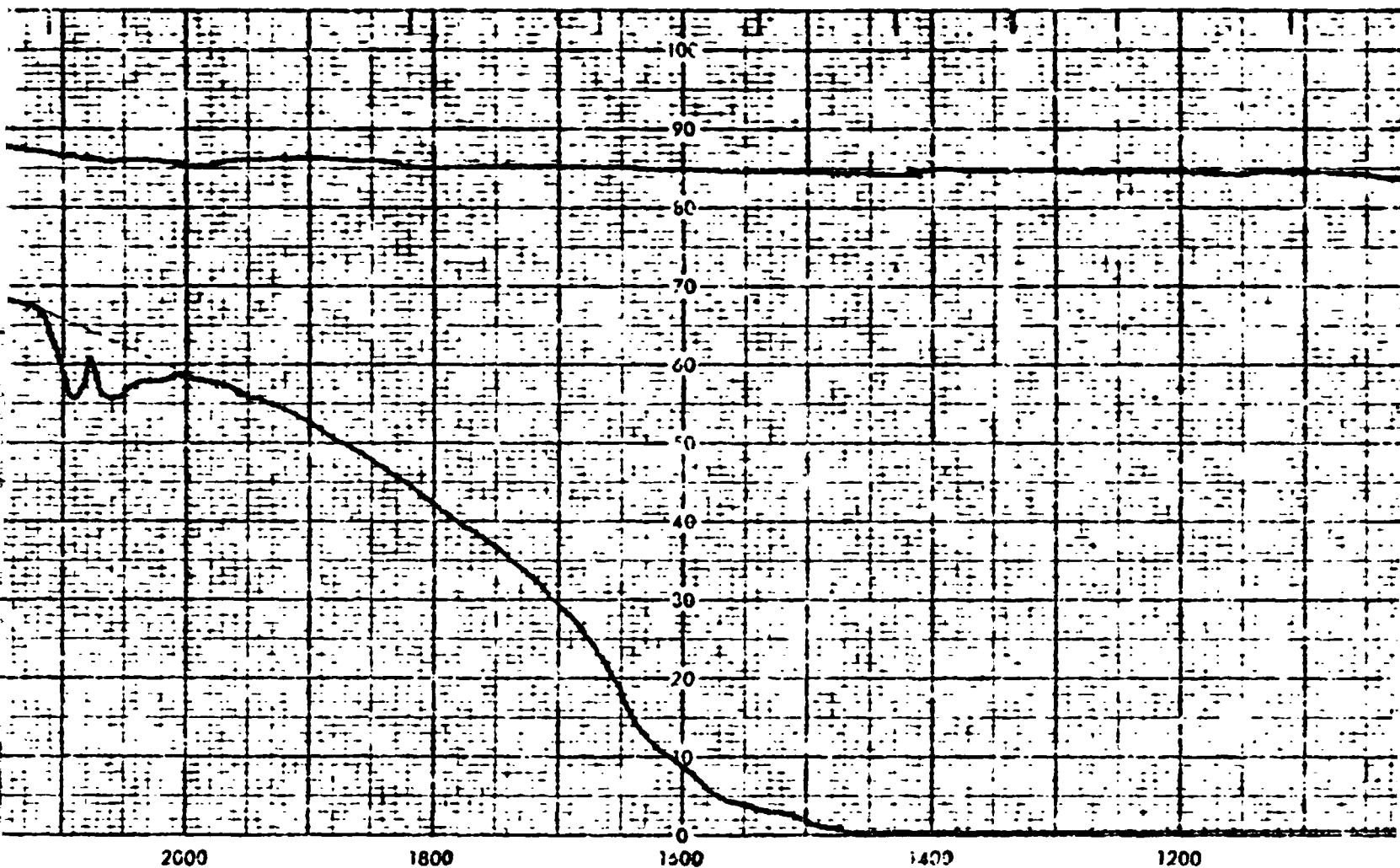
6.5

7

7.5

8

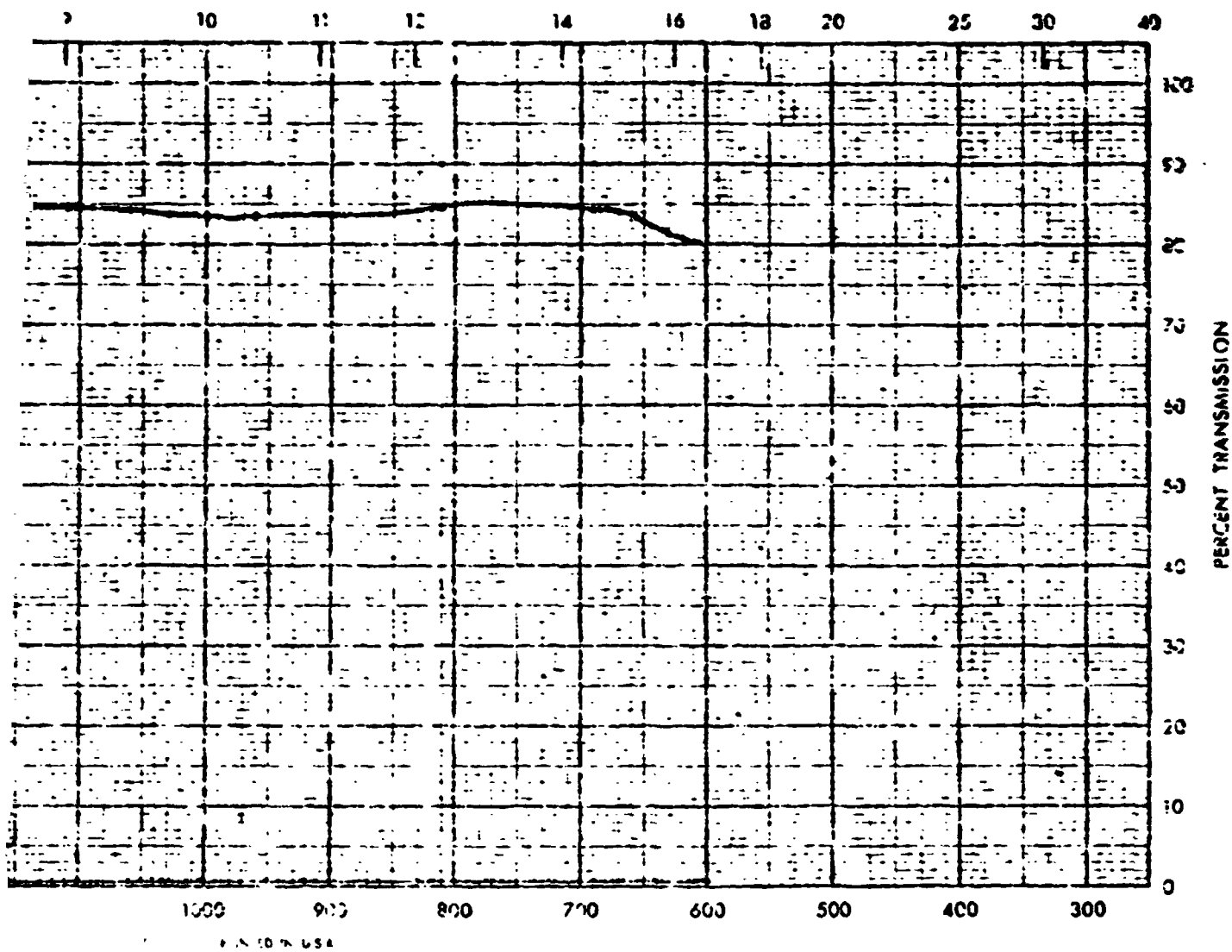
9



NO. 570000

WAVENUMBER CM⁻¹

BECKMAN INSTRUMENTS INC. FULLERTON, CALIFORNIA U.S.A.



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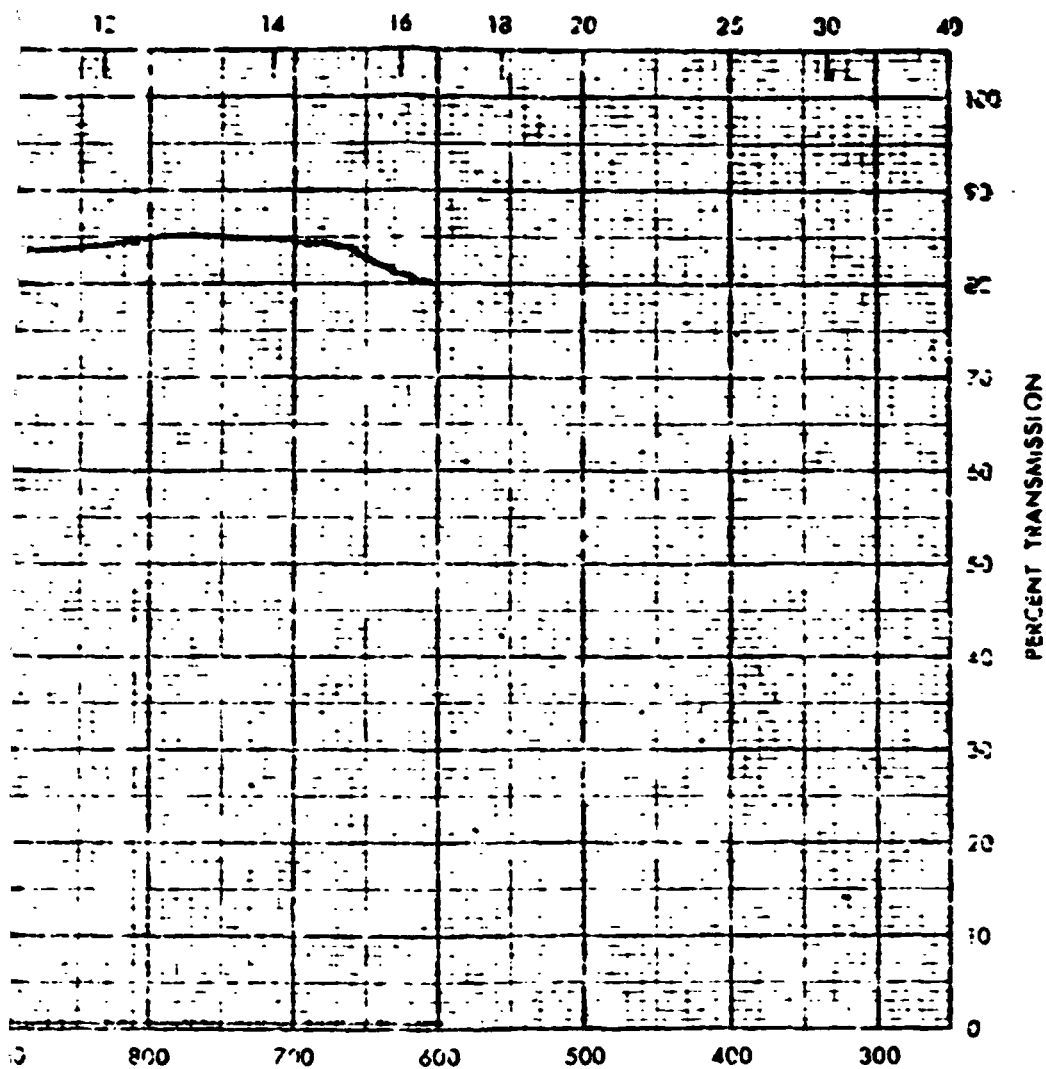
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PHASE

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SPECTRUM NO. B-02973

DATE 3/18/76

SAMPLE GAS CELL 3/11/10

SOURCE _____

STRUCTURE _____

PATH _____

SOLVENT _____

CONCENTRATION _____

PHASE _____

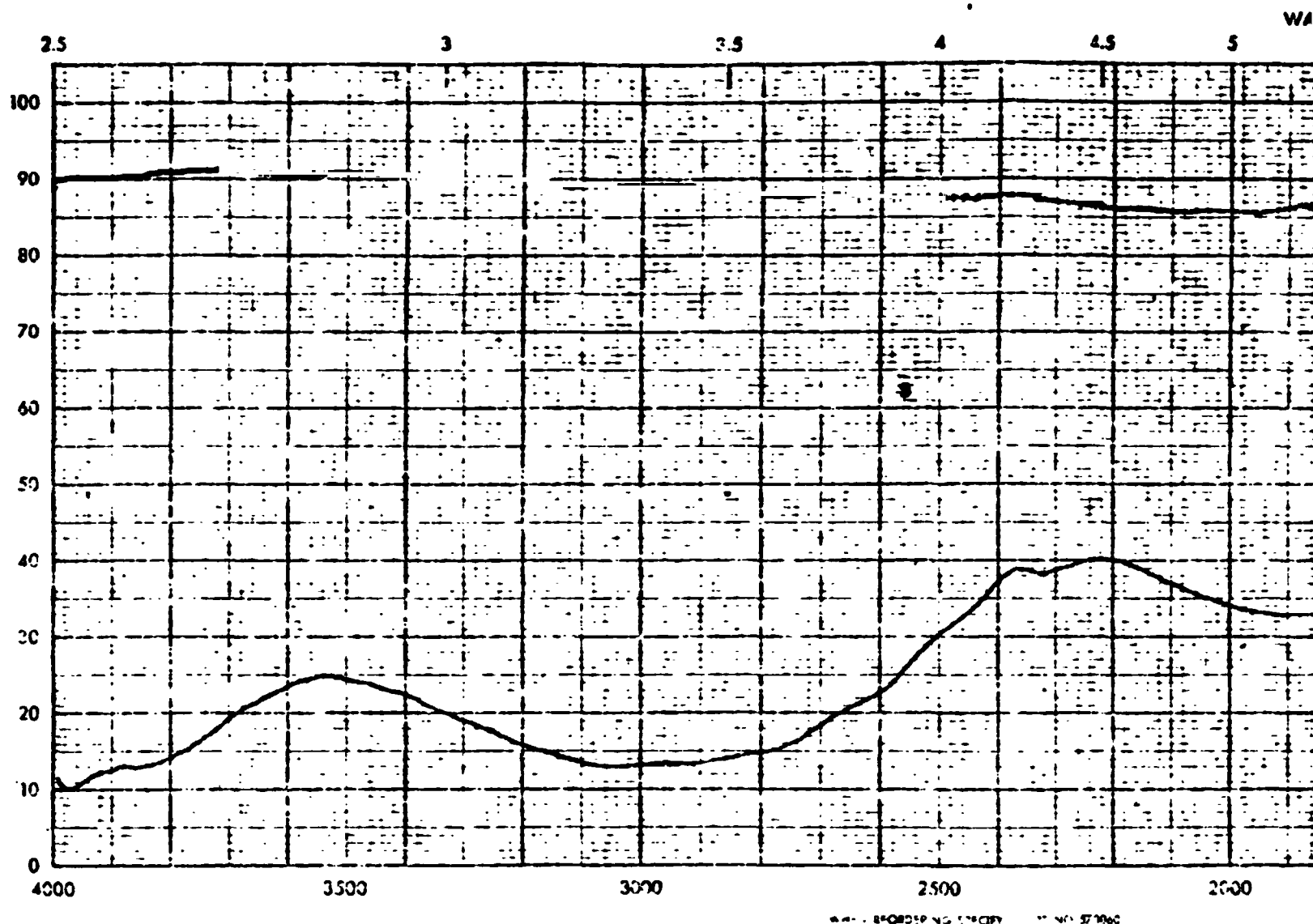
COMMENTS _____

ANALYST KENNEDY

Beckman

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SPECTROPHOTOMETER

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OF POOR QUALITY



FOLDOUT FRAME

WAVELENGTH IN MICRONS

5.5

6

6.5

7

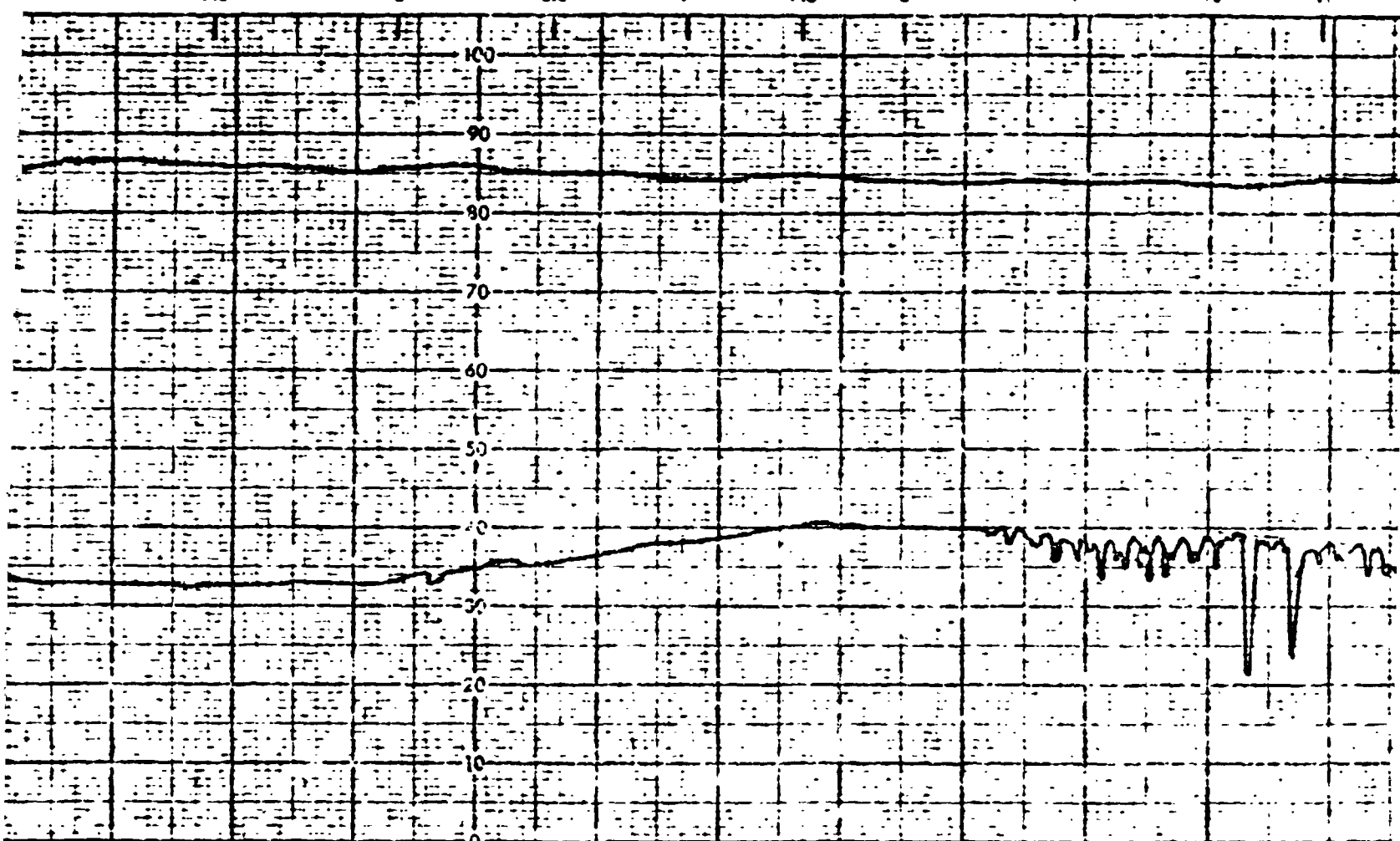
7.5

8

9

10

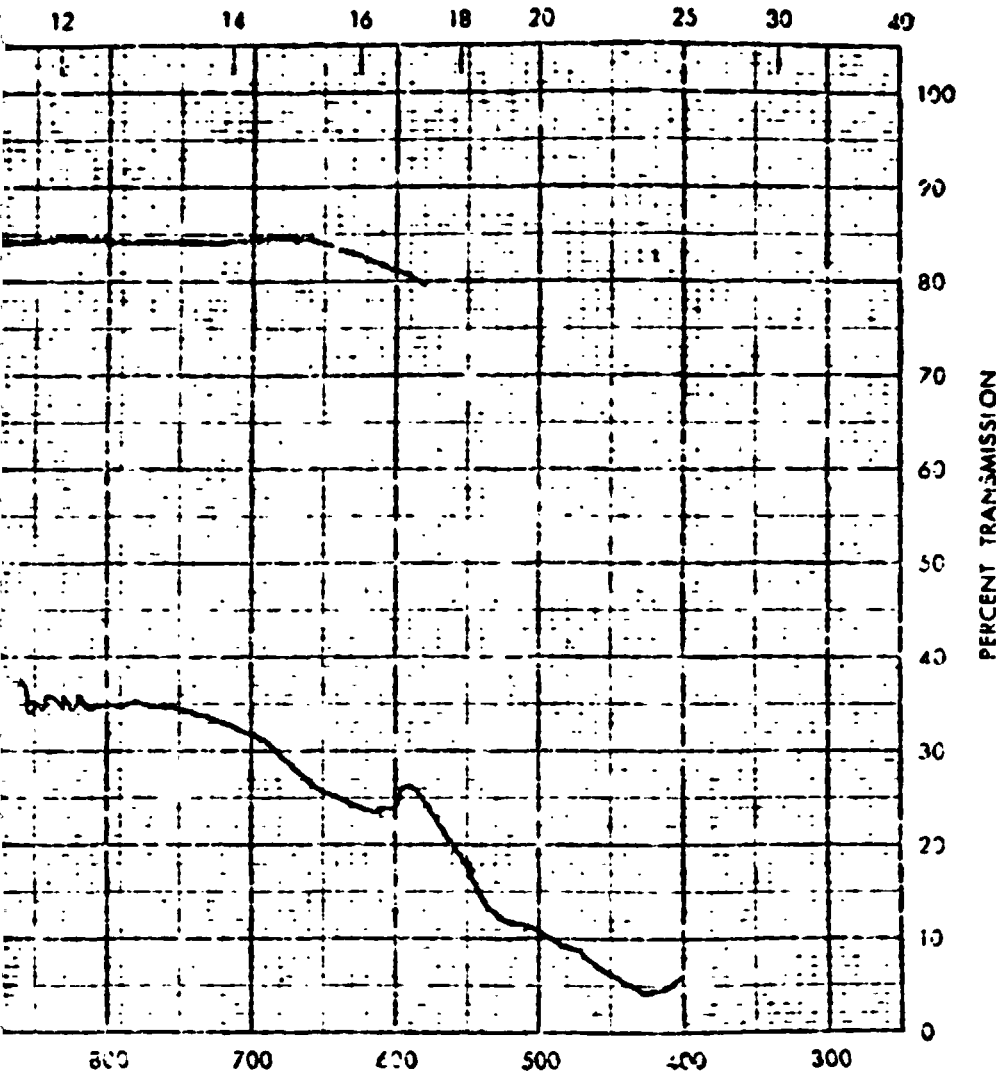
11



WAVENUMBER CM⁻¹

BECKMAN INSTRUMENTS INC. FULLERTON, CALIF. 92631

8-107-10-1



SPECTRUM NO. B-02974
DATE 3/18/76
SAMPLE GAS CELL 3/1 112

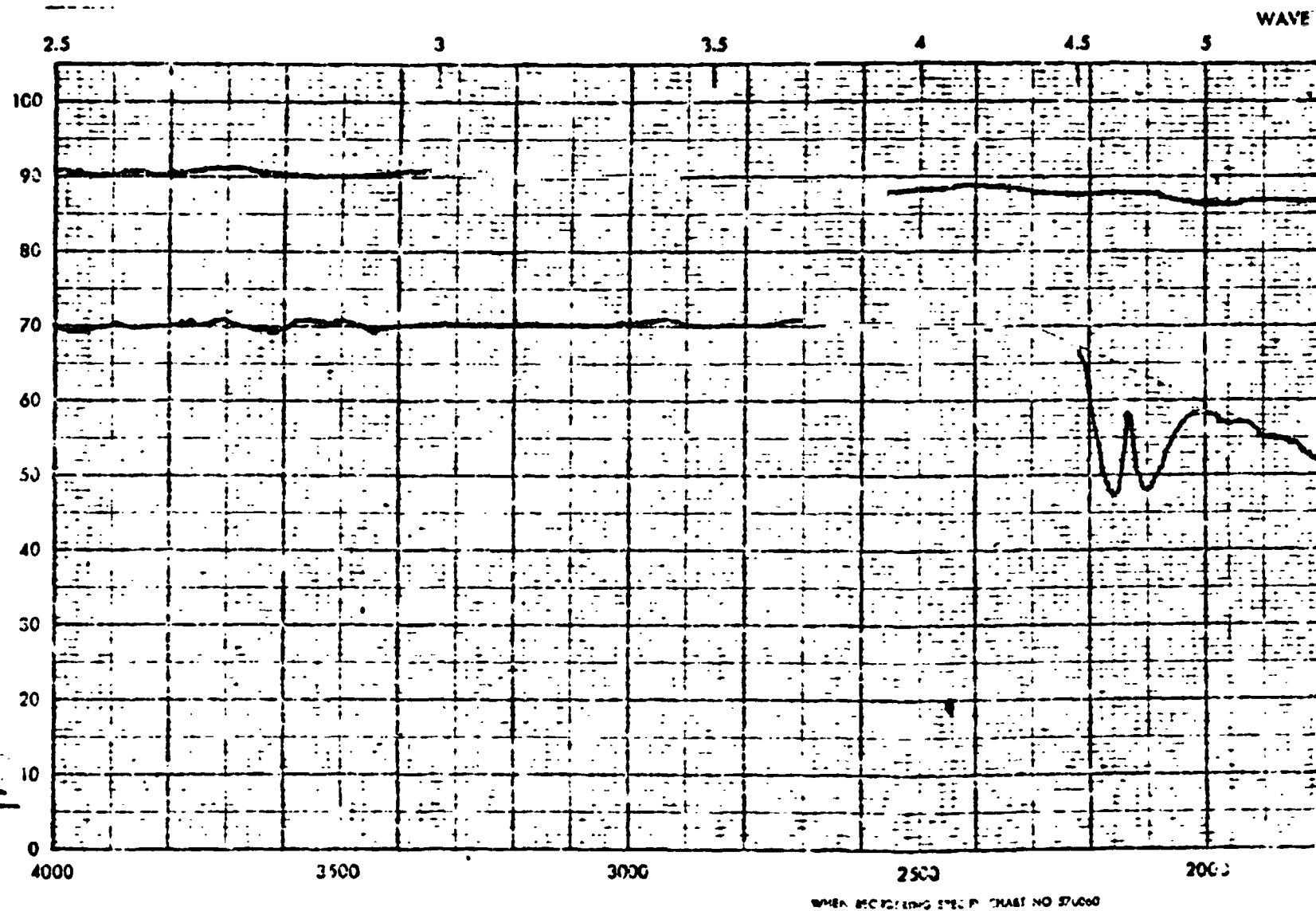
SOURCE _____
STRUCTURE _____

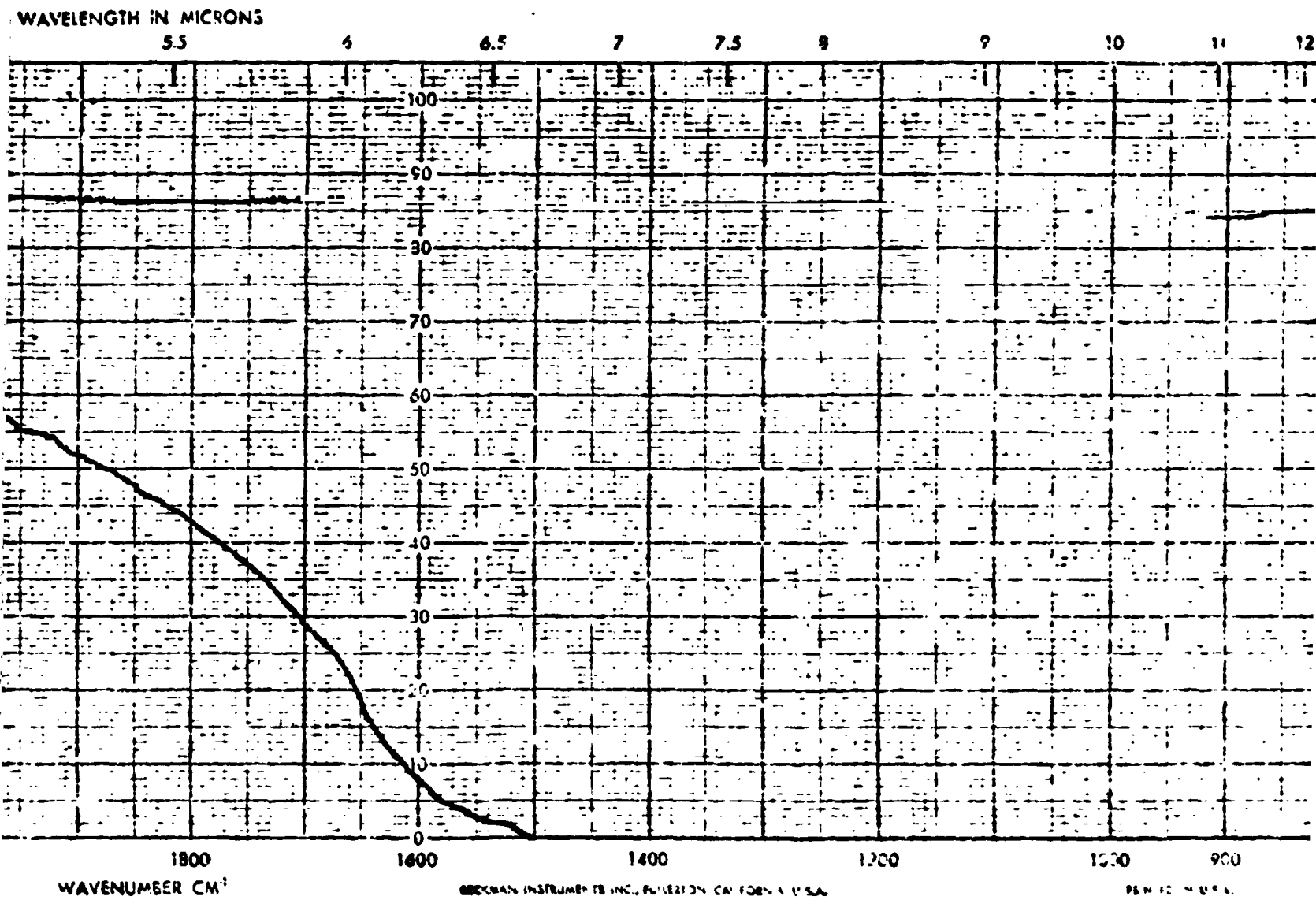
PATH _____
SOLVENT _____
CONCENTRATION _____
PHASE _____
COMMENTS _____

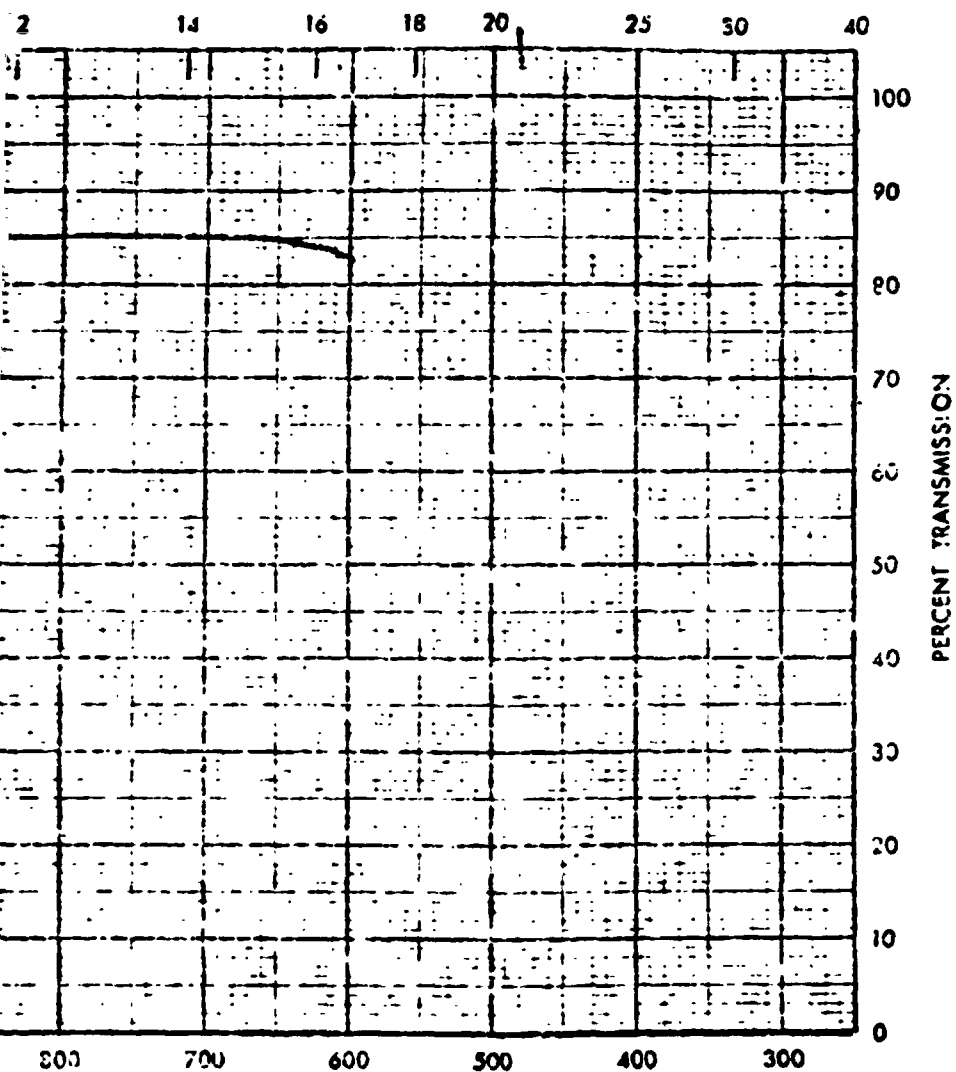
33
ANALYST KENNEDY

Beckman

INFRARED
SPECTROPHOTOMETER







SPECTRUM NO. B-02981

DATE 3/22/76

SAMPLE CAH CELL 3/11 108

SOURCE _____

STRUCTURE _____

PATH _____ mm

SOLVENT _____

CONCENTRATION _____

PHASE _____

COMMENTS AFTER 16914

CHECK/G 90 2.500

VACUUM EXPOSURE

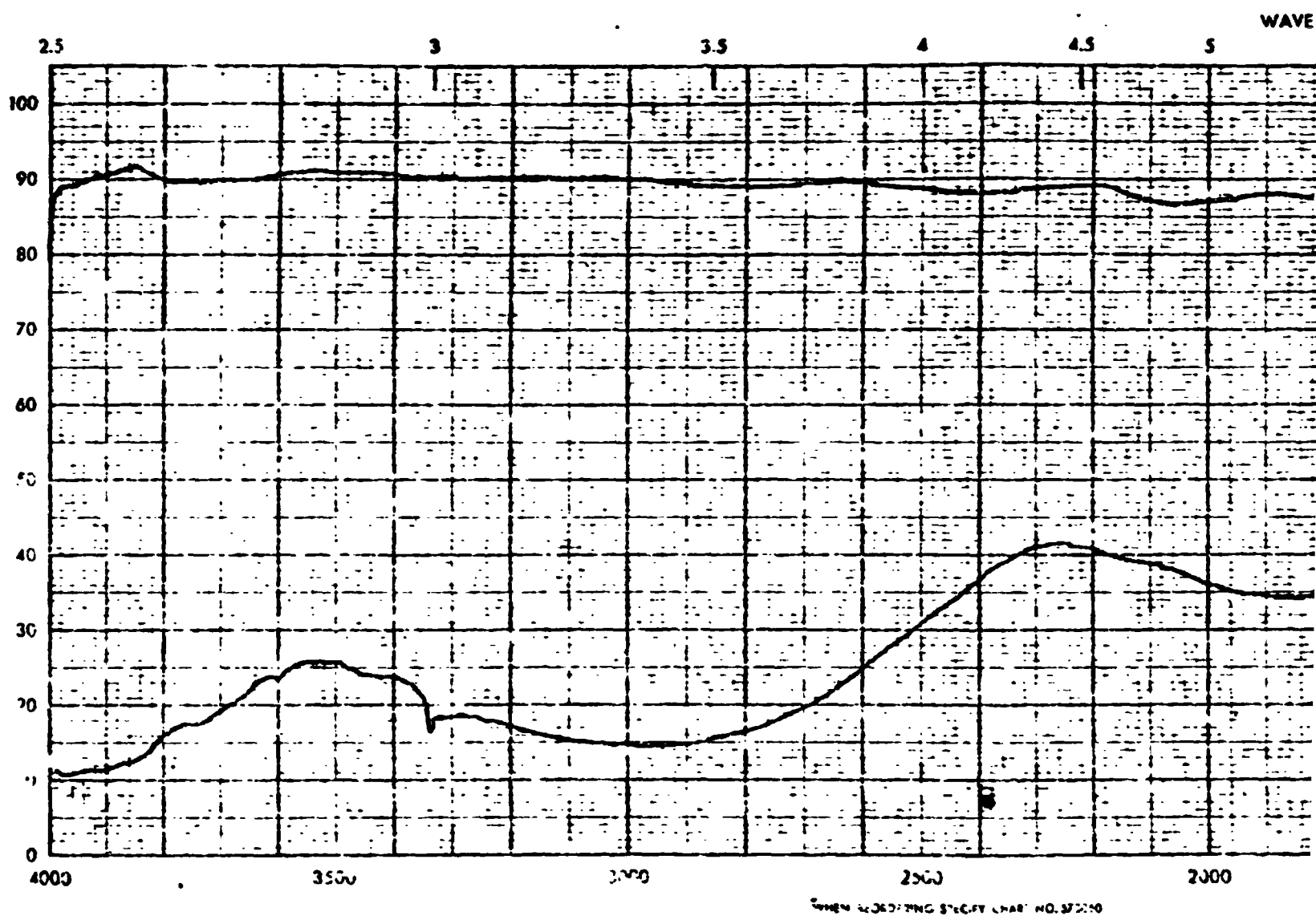
TEST

ANALYST KENNEDY

Beckman®

INFRARED
SPECTROPHOTOMETER

ORIGINAL PAGE IS
OF POOR QUALITY



FOLDOUT FRAME

WAVELENGTH IN MICRONS

5.5

6

6.5

7

7.5

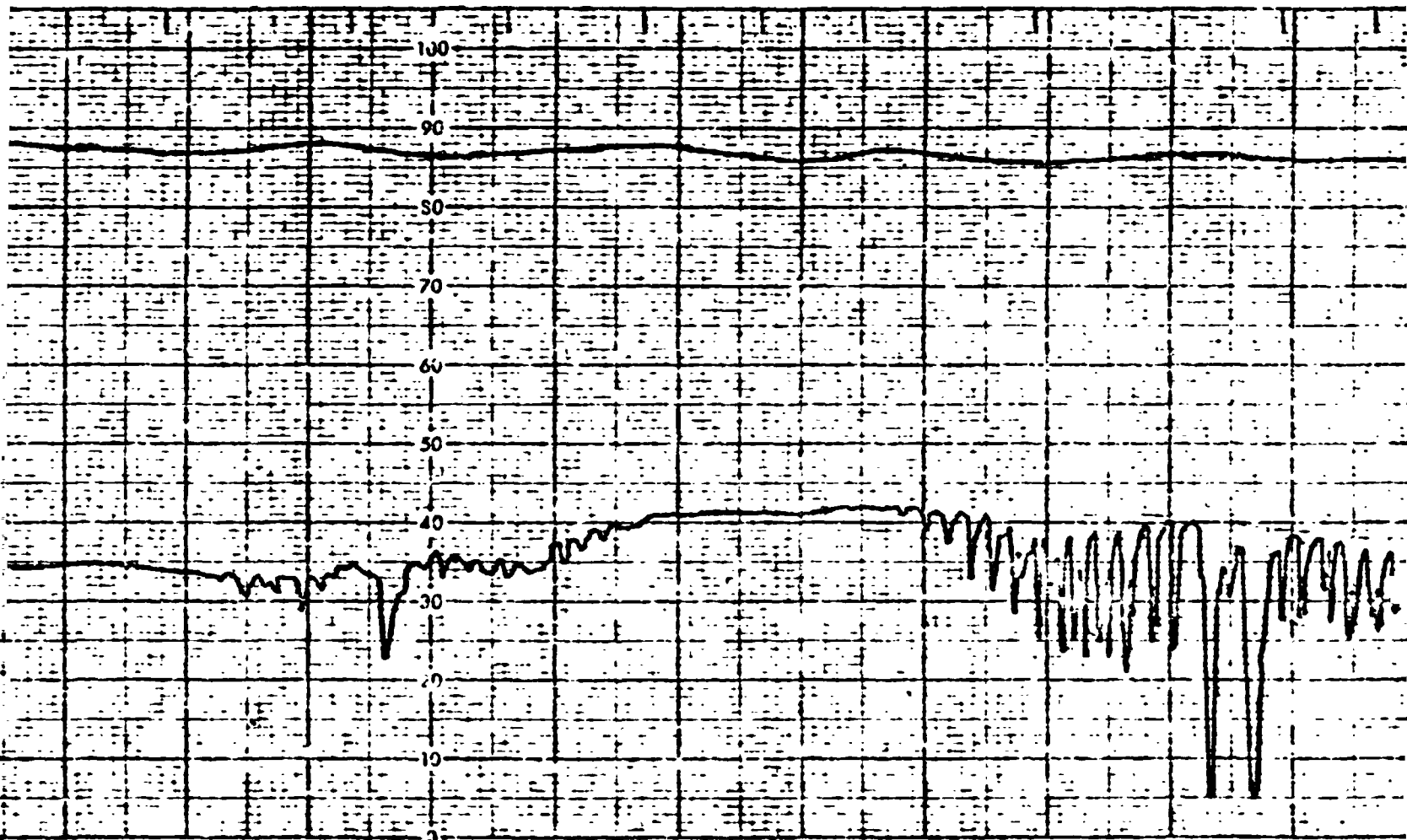
8

9

10

11

12



1800

1500

1400

1200

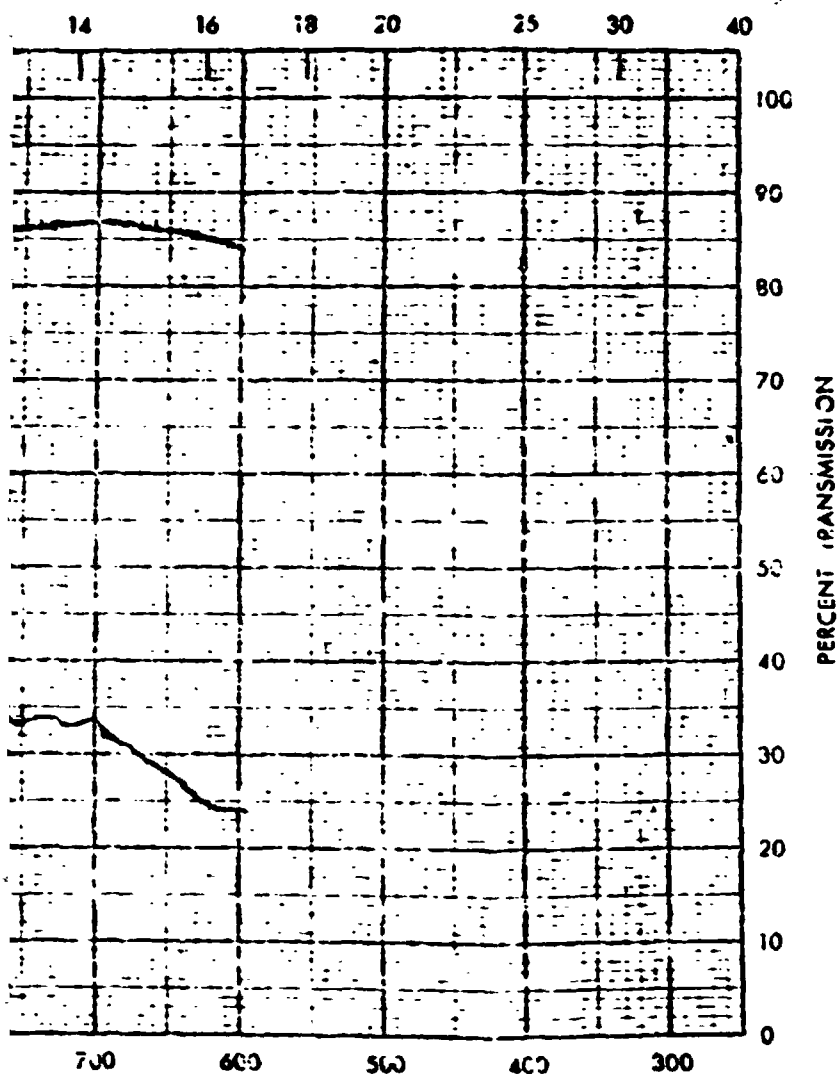
1000

900

WAVENUMBER CM⁻¹

BECKMAN INSTRUMENTS INC., FULLERTON, CALIFORNIA, U.S.A.

PERIOD 14 1964



SPECTRUM NO. B-02975

DATE 3/22/76

SAMPLE CAS CELL 3/H 109

SOURCE _____

STRUCTURE _____

PATH _____ cm

SOLVENT _____

CONCENTRATION _____

PHASE _____

COMMENTS AFT. LERK

CHECK/VACUUM EXPOSURE

1.75 @ 97%

ANALYST KENNEDY

Beckman

INFRARED
SPECTROPHOTOMETER

WAVELENGTH

25

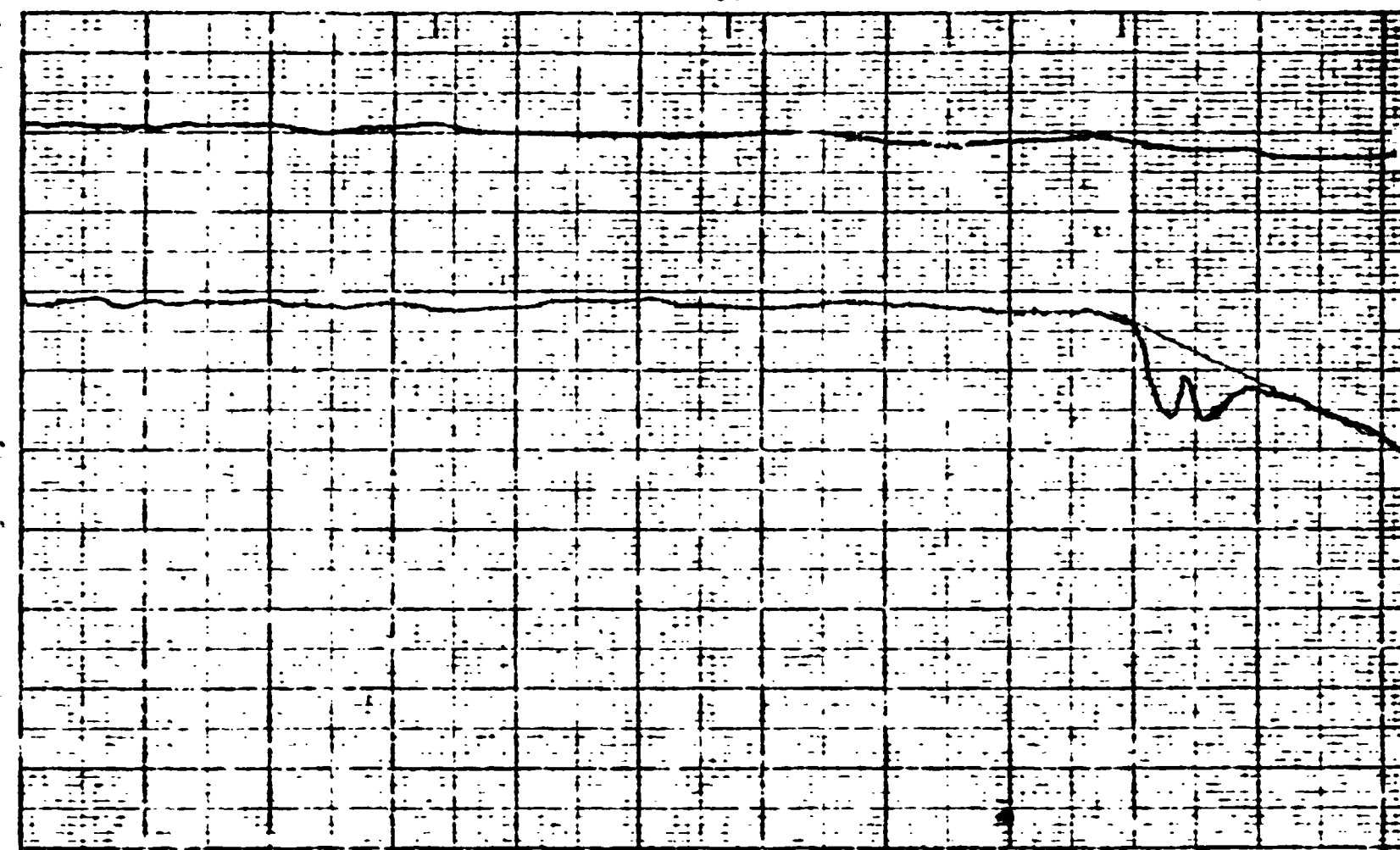
1

35

4

45

5



WAVELENGTH SPECIFY UNIT NO. 570092

WA

FOLDOUT FRAME

WAVELENGTH IN MICRONS

5.5

6

6.5

7

7.5

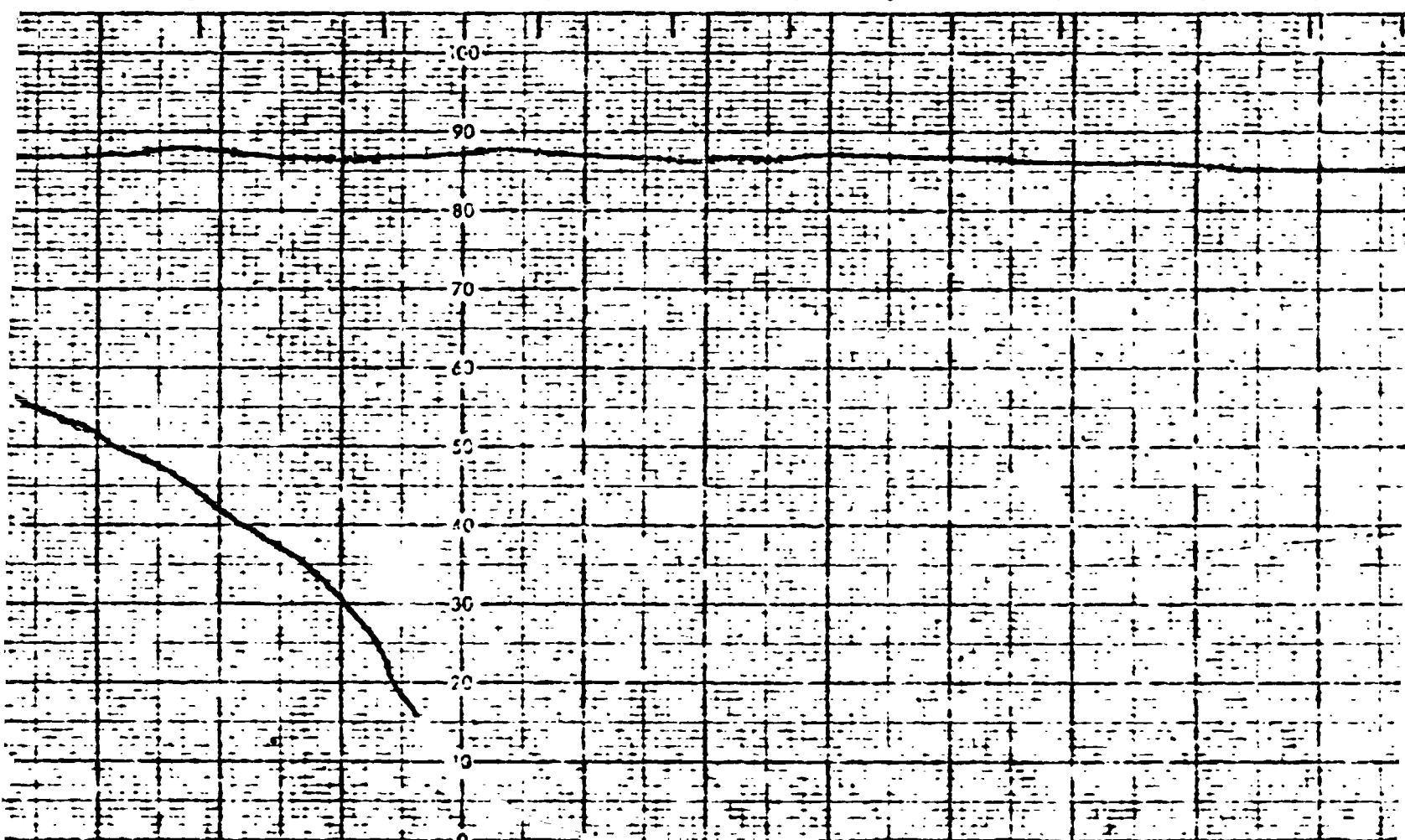
8

9

10

11

12



1800

1600

1400

1200

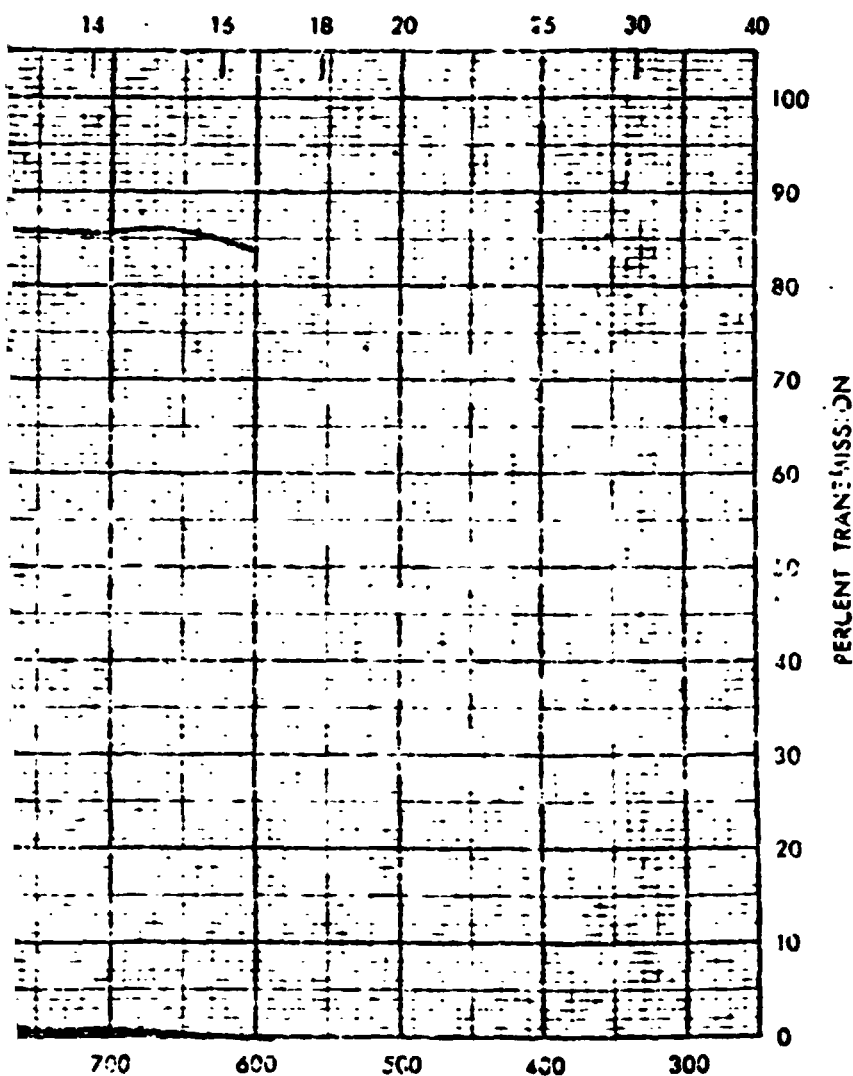
1000

900

WAVENUMBER CM⁻¹

BECKMAN INSTRUMENTS INC. FULLERTON, CALIFORNIA, U.S.A.

PRINTED IN U.S.A.



SPECTRUM NO. B-02986

DATE 3/22/76

SAMPLE GAS CELL 3/11/10

SOURCE _____

STRUCTURE _____

PATH _____ mm

SOLVENT _____

CONCENTRATION _____

PHASE _____

COMMENTS AFTER LEAK _____

CHECK / VACUUM 22865096

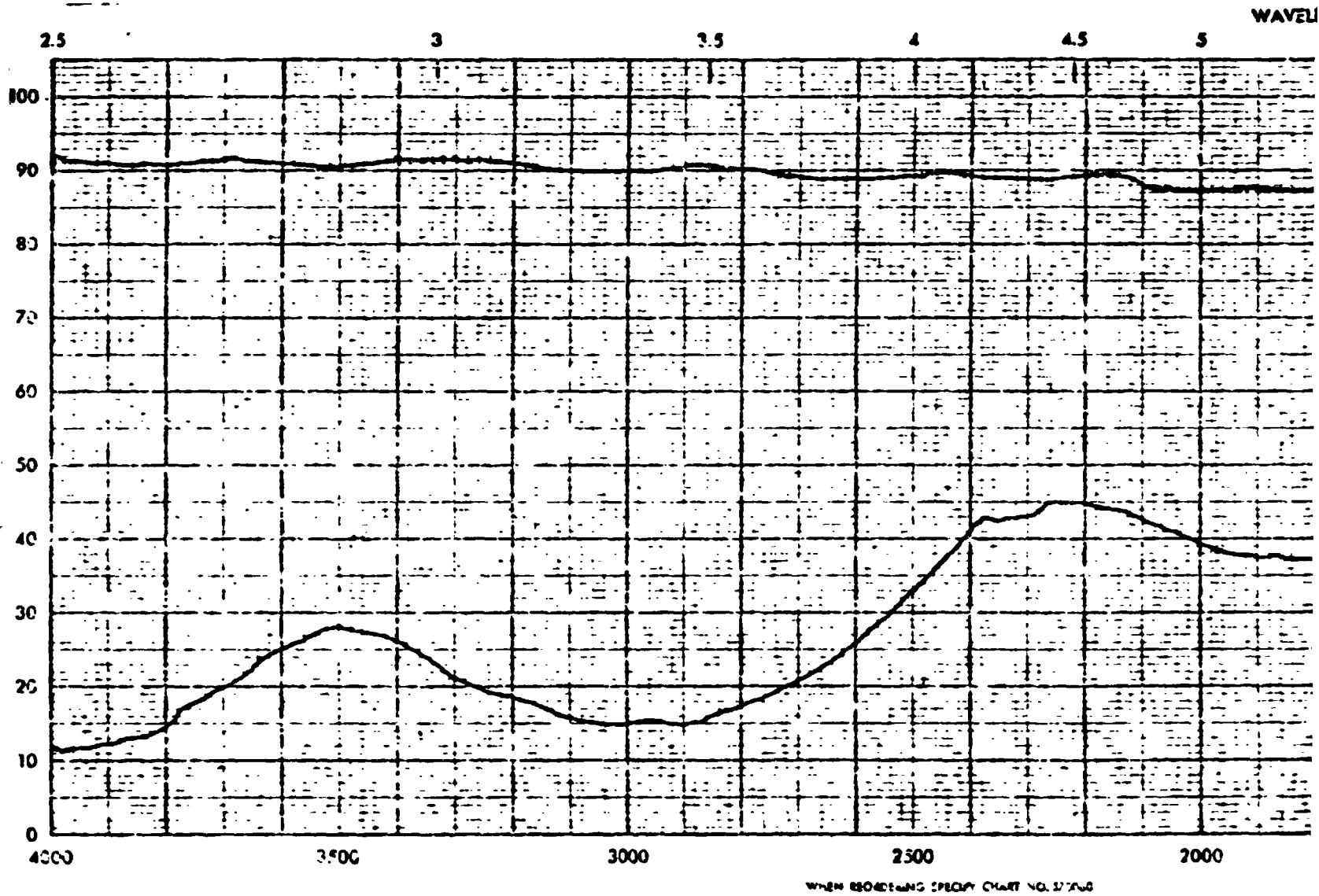
49.8 21500

ANALYST KENNEDY

Beckman®

INFRARED
SPECTROPHOTOMETER

ORIGINAL PAGE IS
OF POOR QUALITY



FOLDOUT FRAME

WAVELENGTH IN MICRONS

5.5

6

6.5

7

7.5

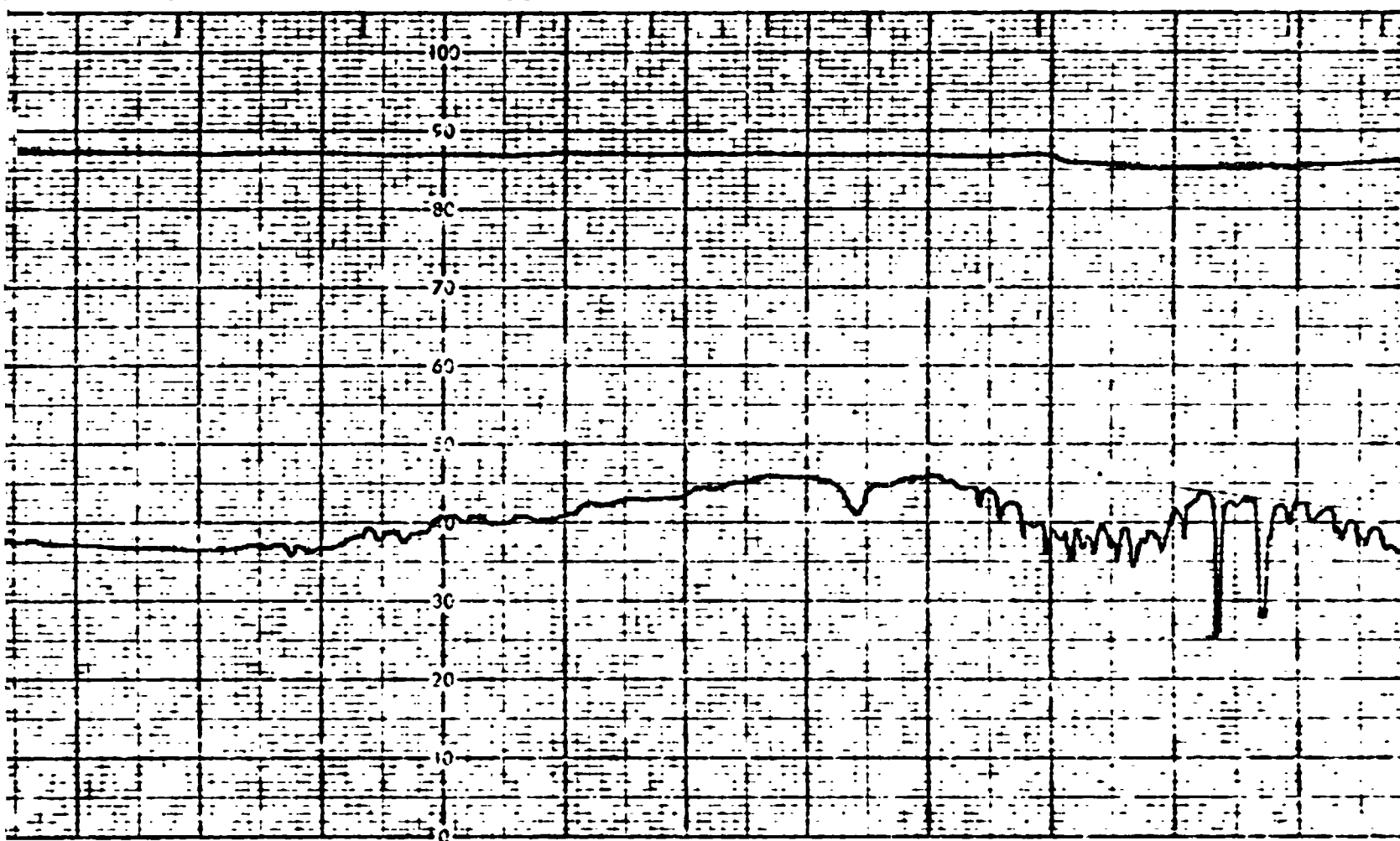
8

9

10

11

12

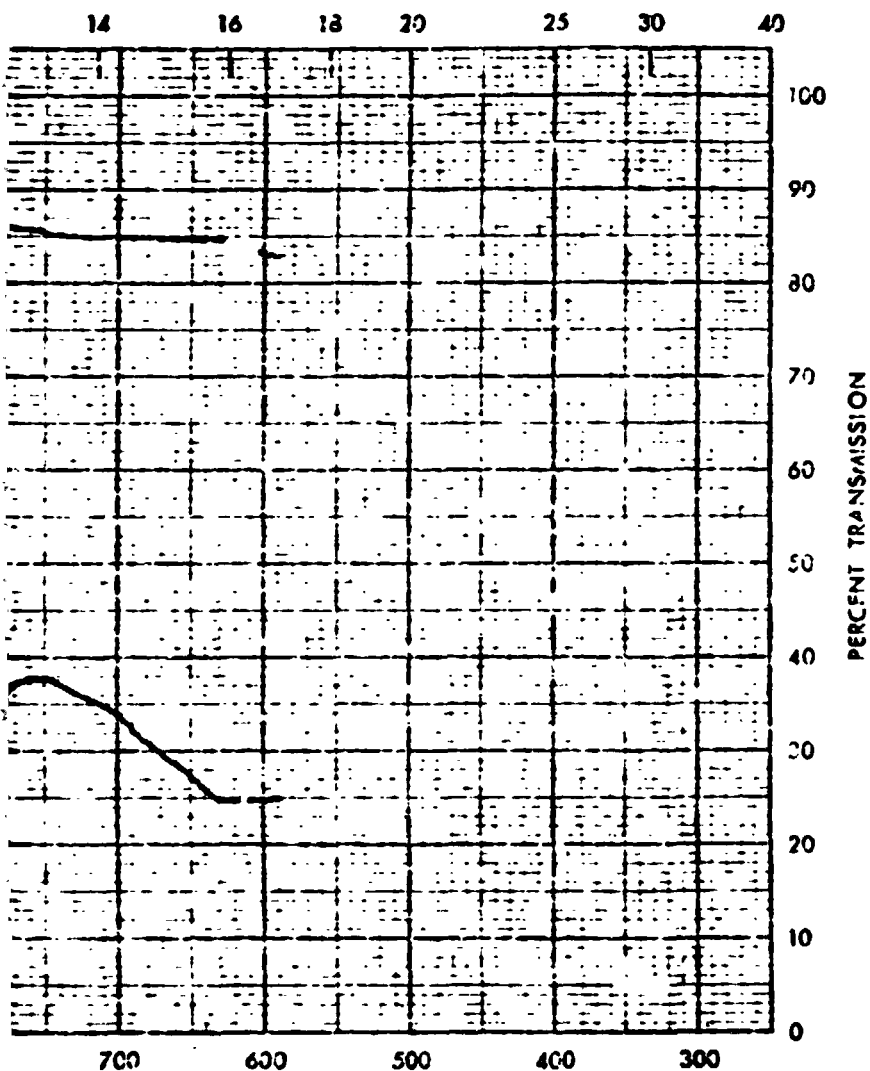


WAVENUMBER CM⁻¹

BECKMAN INSTRUMENTS INC., FULLERTON, CALIFORNIA, U.S.A.

Model No. IR-9

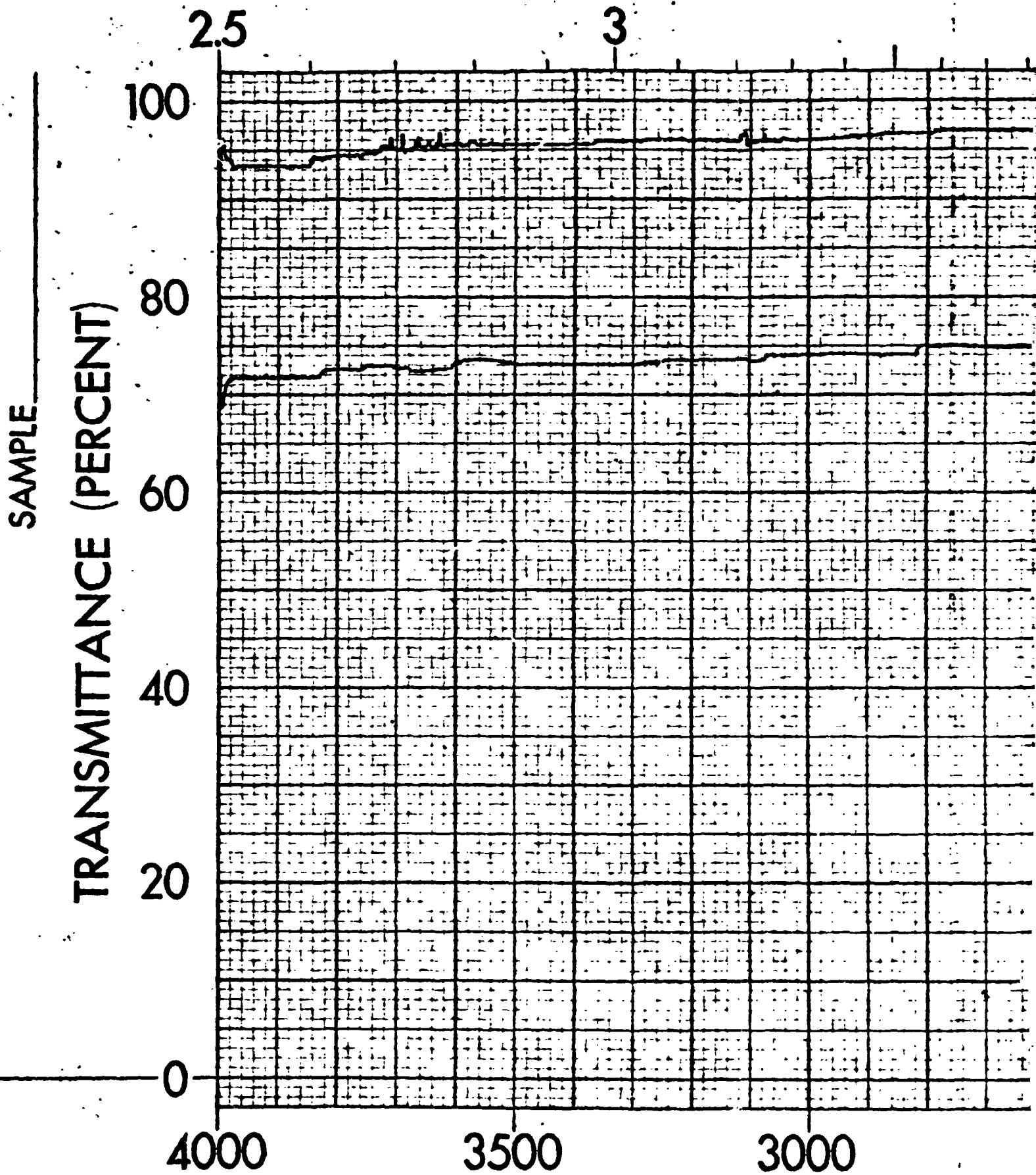
EXDOUT FRAME 2



SPECTRUM NO. B-02287
 DATE 3/22/76
 SAMPLE SAS COU 5/112
 SOURCE _____
 STRUCTURE _____
 PATH _____ mm _____
 SOLVENT _____
 CONCENTRATION _____
 PHASE _____
 COMMENTS AFTER LEAK
CHECK/VACUUM EXPOSURE
.93
 ANALYST ICENHEDY
Beckman®
 INFRARED
 SPECTROPHOTOMETER

11#

ORIGINAL PAGE IS
OF POOR QUALITY



WAVELENGTH (MICRONS)

4

5

6

100

100

CARBON DIOXIDE
CONTAMINATION
ON INSTRUMENT
MIRRORS

80

80

60

60

40

40

20

20

0

0

2500

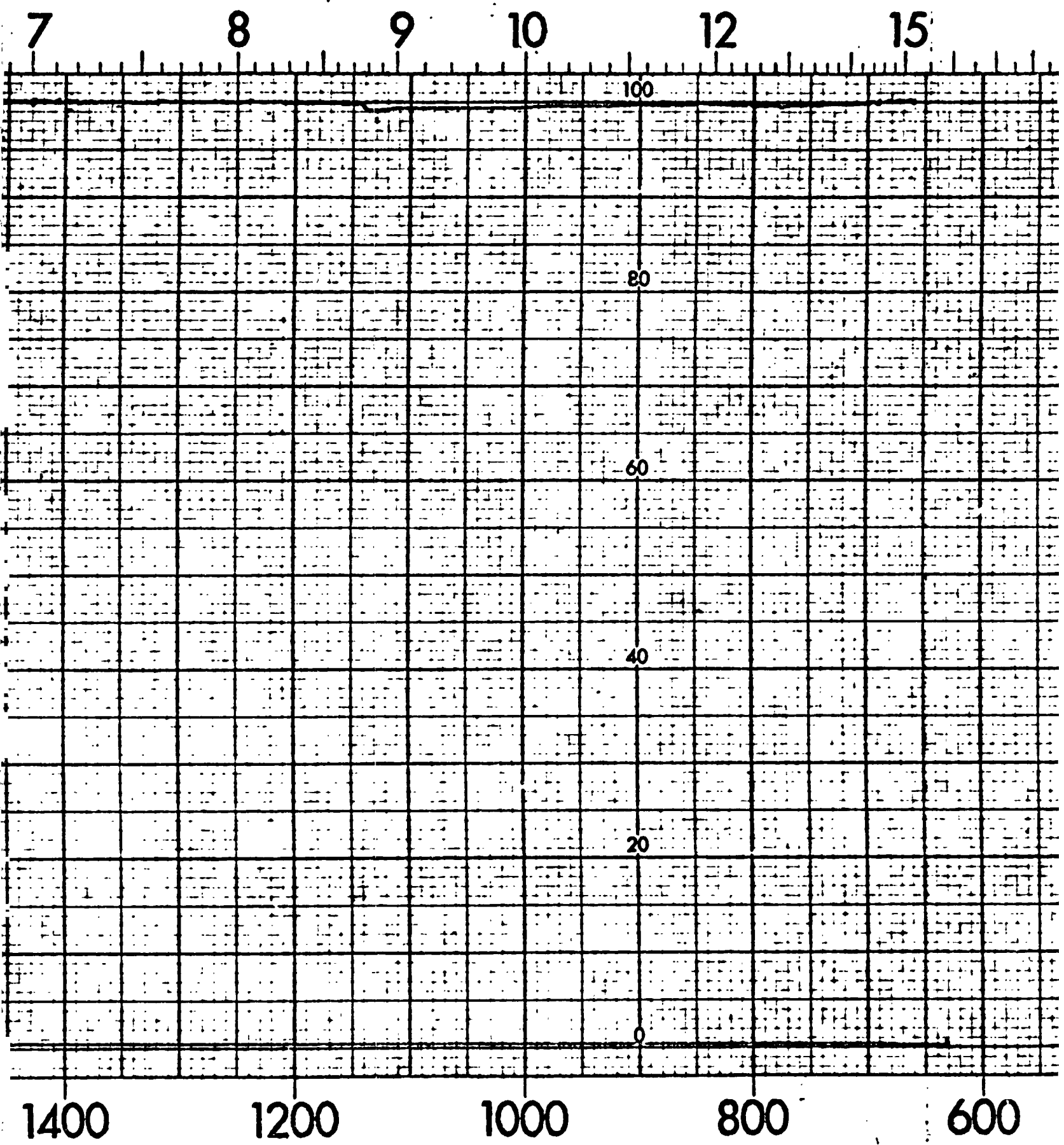
2000

1800

1600

WAVENUMBER (CM⁻¹)

3)



20

30

40

100

80

60

40

20

10

PERKIN-ELMER®

600

400

200

SPECTRUM NO. _____

SAMPLE GAS CELL S/H 108

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 4/9/76

OPERATOR _____

REMARKS AFTER LIFE TEST

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

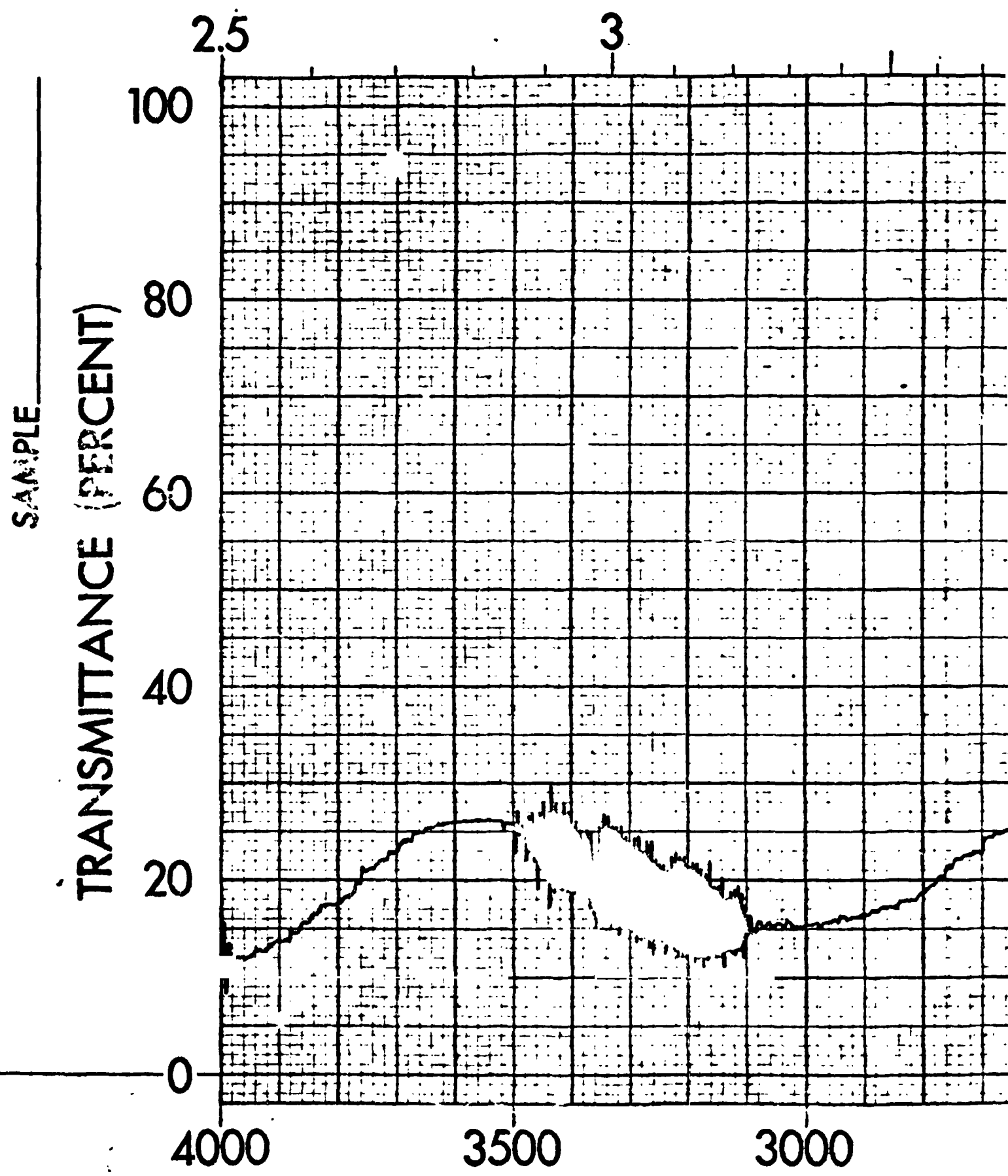
SUPPRESSION _____

SCALE EXPANSION _____

SOURCE CURRENT _____

NO. 221-1607

h' #



WAVELENGTH (MICRONS)

4

5

6

100

80

60

40

20

0

60

40

20

0

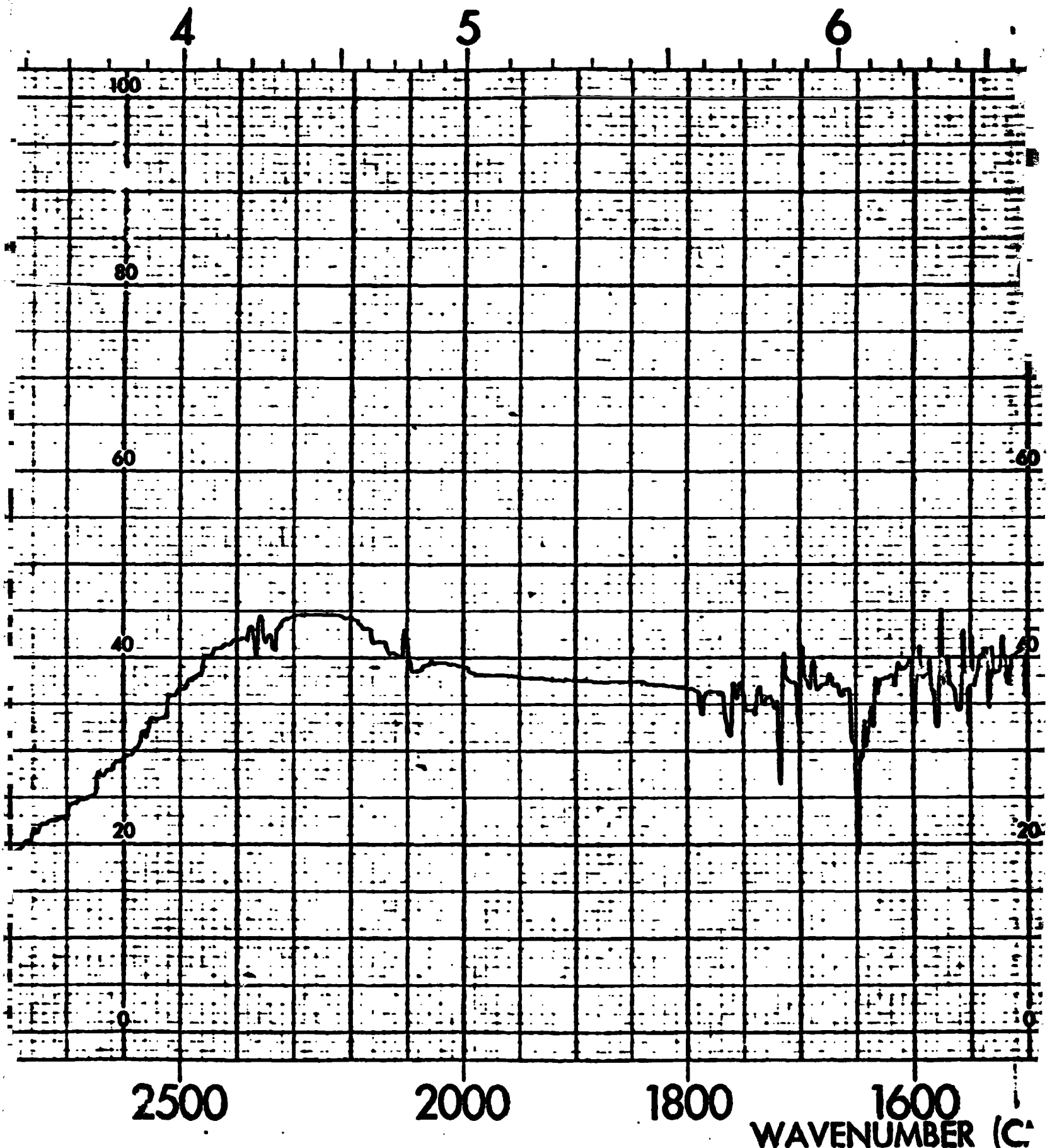
2500

2000

1800

1600

WAVENUMBER (CM⁻¹)



CRONS)

7

8

9

10

12

15

100

100

80

80

60

60

20

20

0

0

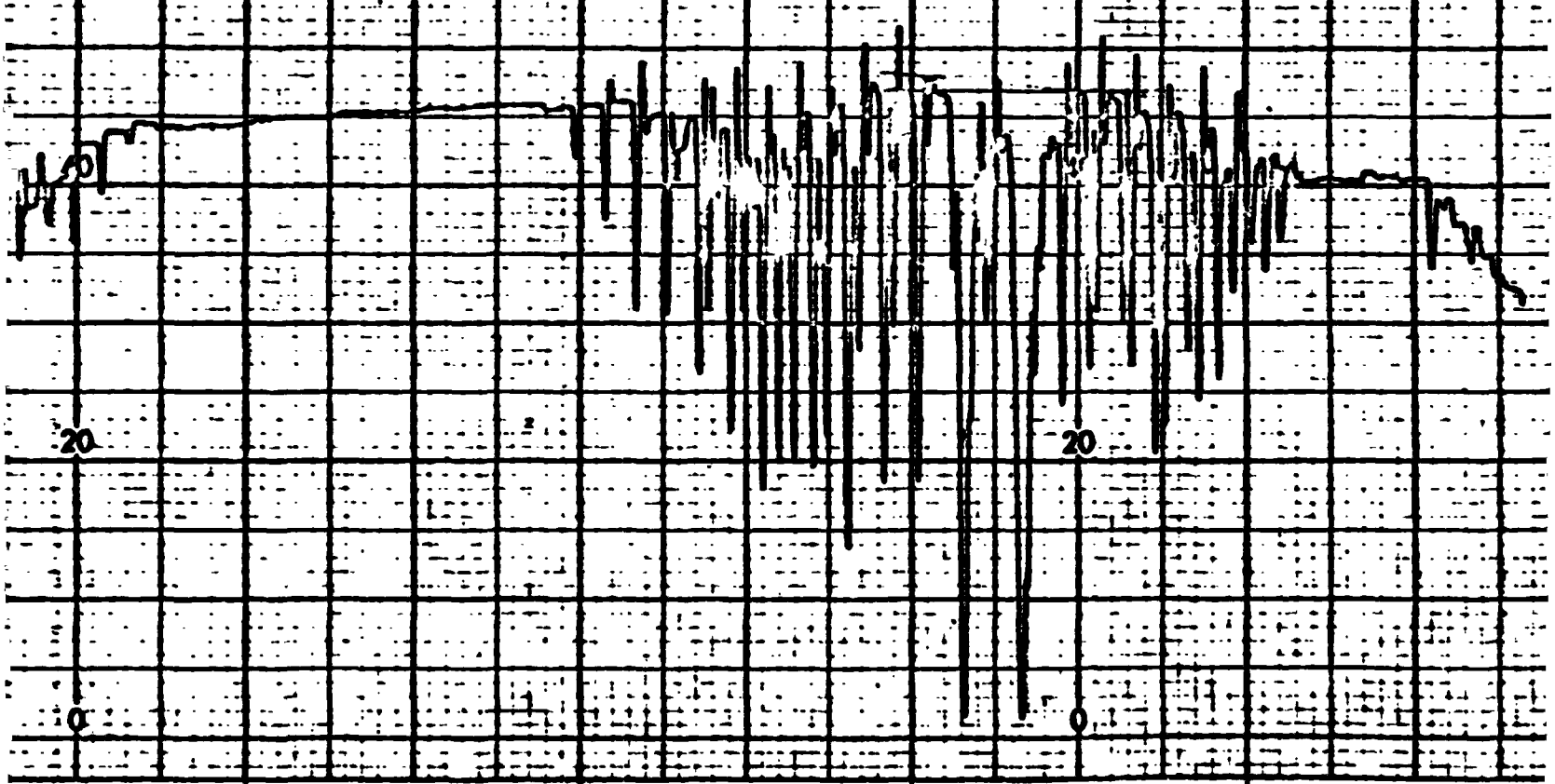
1400

1200

1000

800

(CM⁻¹)





SPECTRUM NO. _____

SAMPLE GAS CELL S/N 109 _____

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 4/9/76 _____

OPERATOR _____

REMARKS AFTER ITEL TEST _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION _____

SOURCE CURRENT _____

C-#

SAMPLE

TRANSMITTANCE (PERCENT)

2.5

3

100

80

60

40

20

0

4000

3500

3000

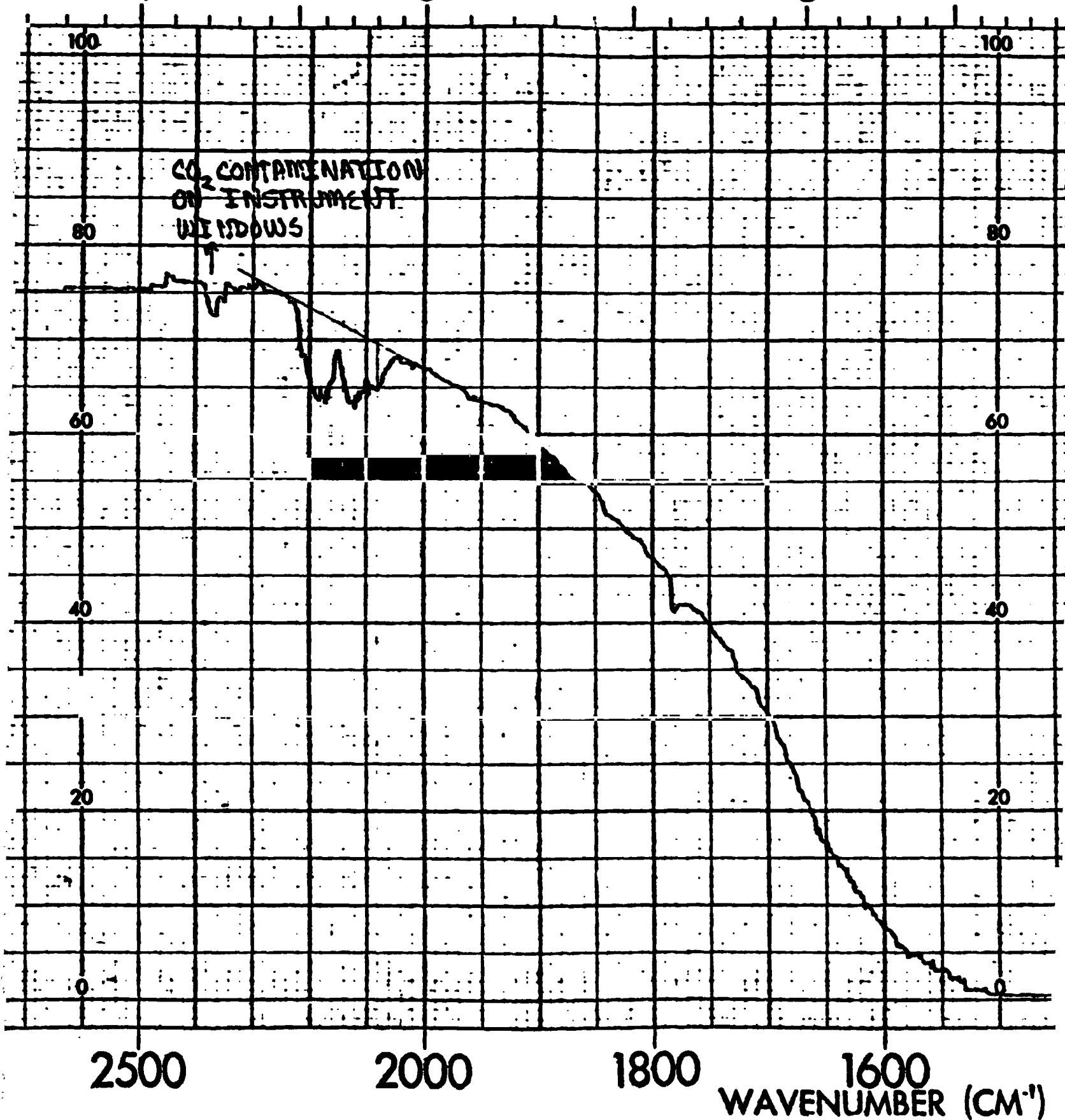
WAVELENGTH (MICRONS)

4

5

6

CO₂ CONTAMINATION
ON INSTRUMENT
WINDOWS



IONS)

7

8

9

10

12

15

100

100

80

80

60

60

40

40

20

20

0

0

1400

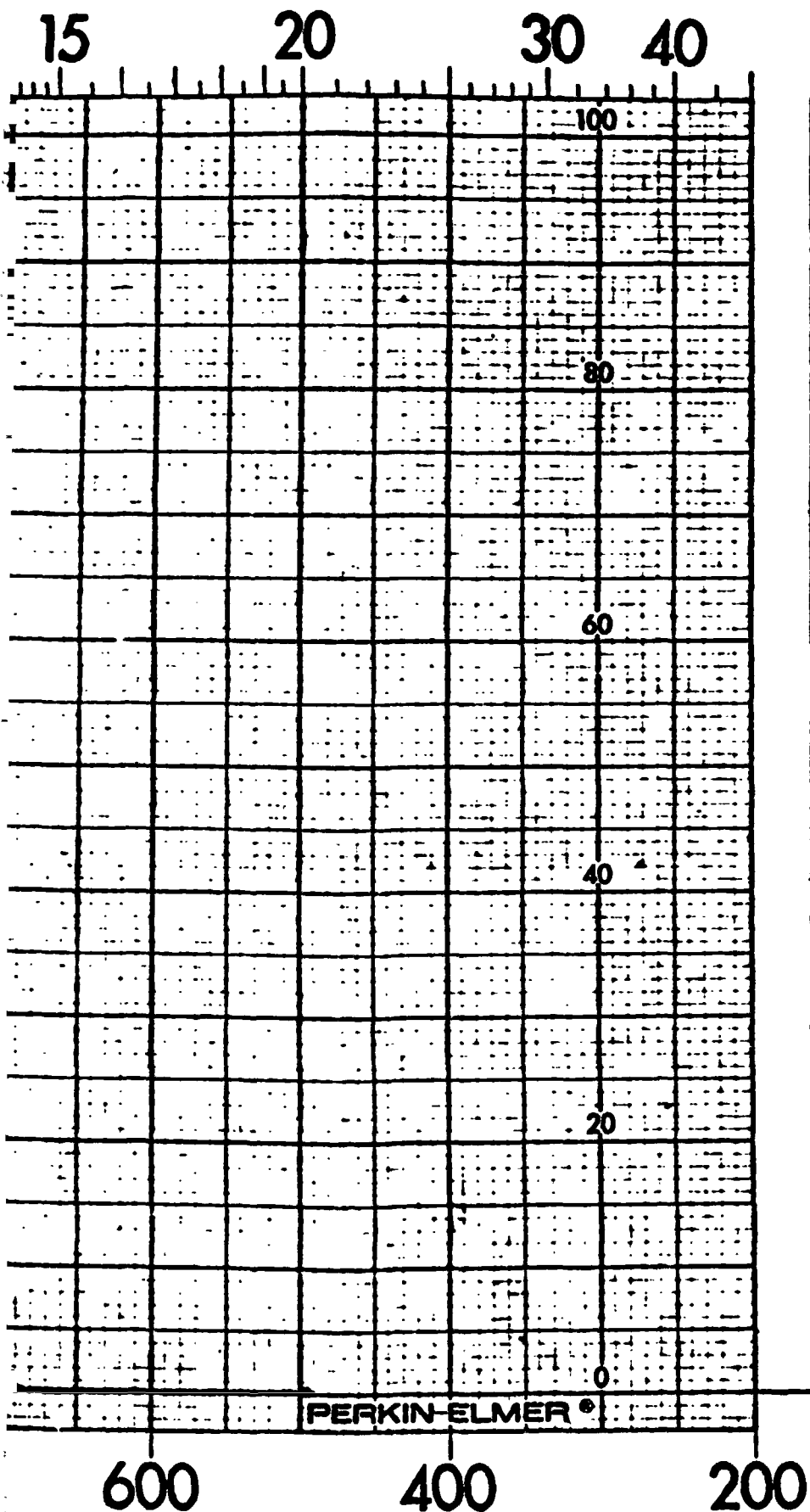
1200

1000

800

6

CM⁻¹)



SPECTRUM NO. _____
SAMPLE GAS CELL S/N 110

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 4/2/76

OPERATOR _____

REMARKS AFTER LIFE TEST

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

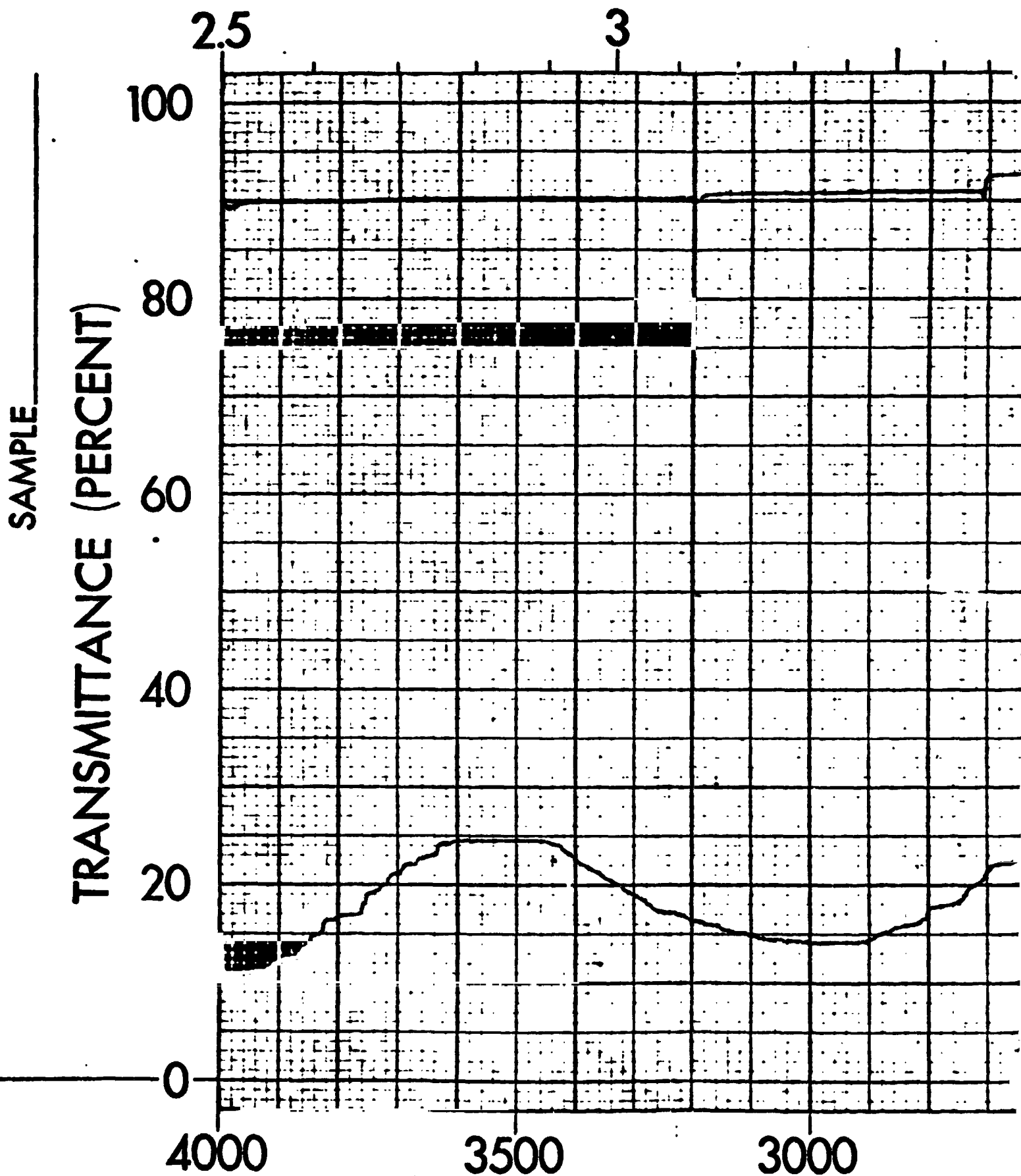
SUPPRESSION _____

SCALE EXPANSION _____

SOURCE CURRENT _____

NO. 221-1607

#12



WAVELENGTH (MICRONS)

4

5

6

100

100

80

80

60

60

40

40

20

20

0

0

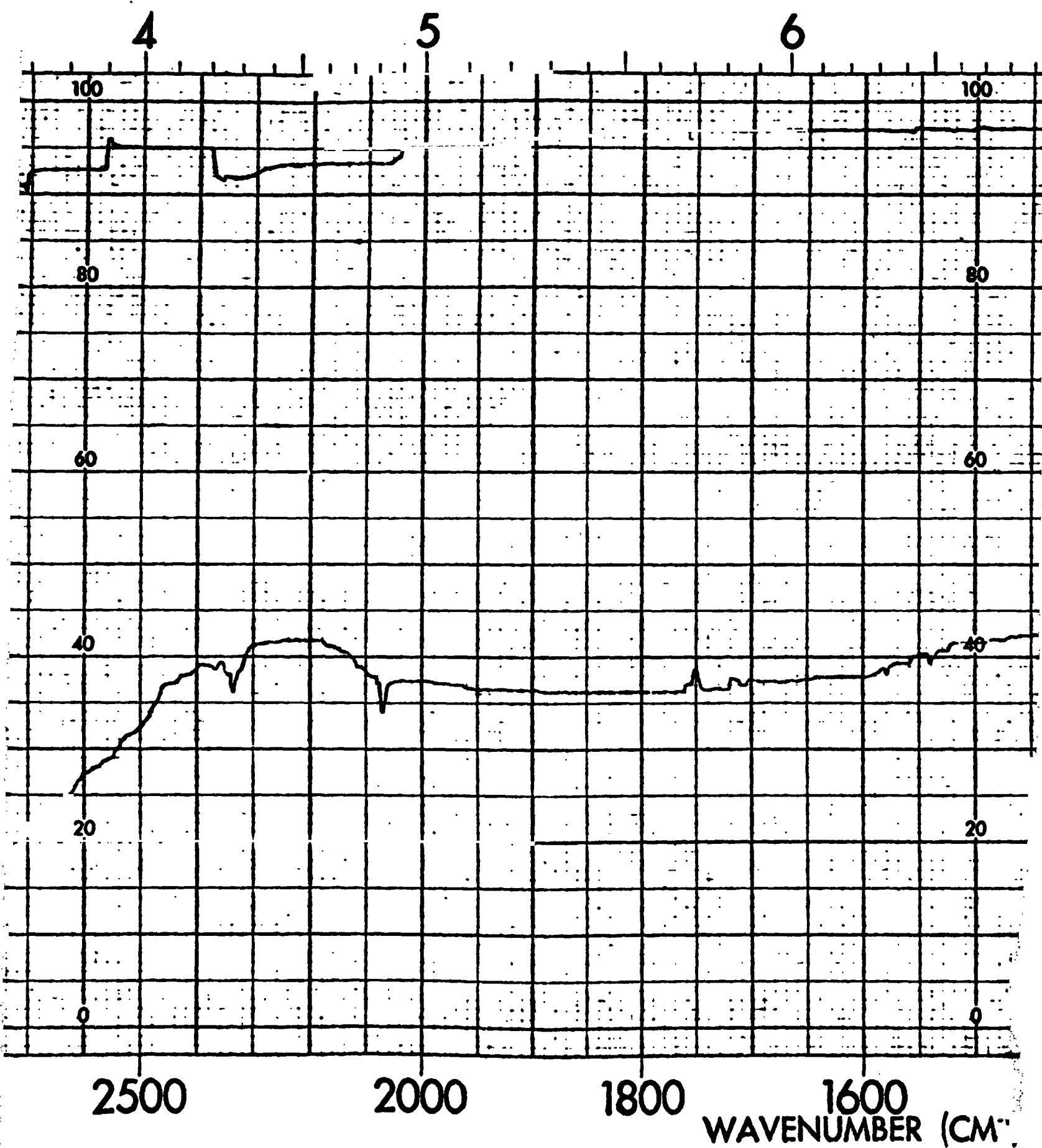
2500

2000

1800

1600

WAVENUMBER (CM⁻¹)



15)

7 8 9 10 12 15

100

80

60

40

20

0

1400

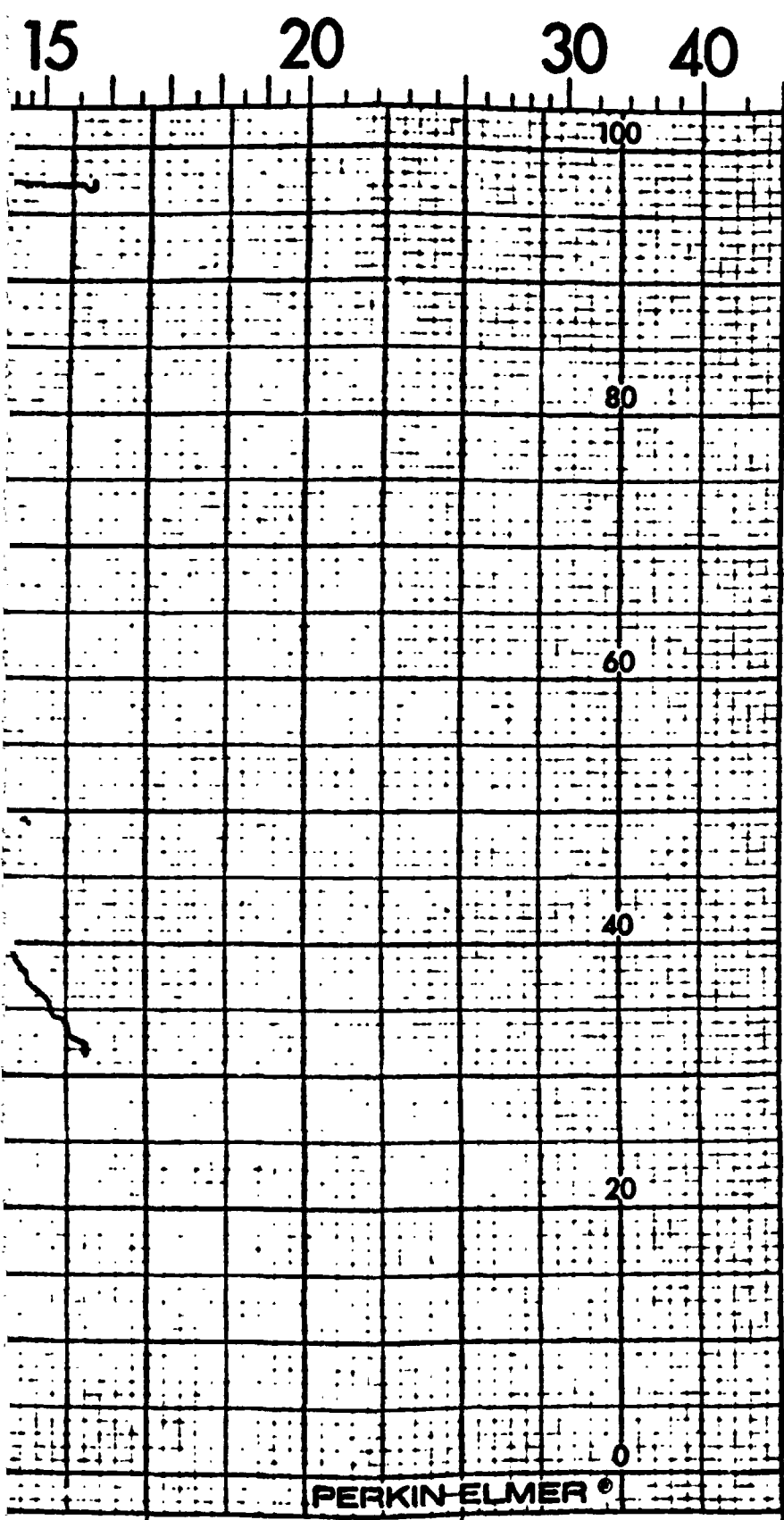
1200

1000

800

600

1)



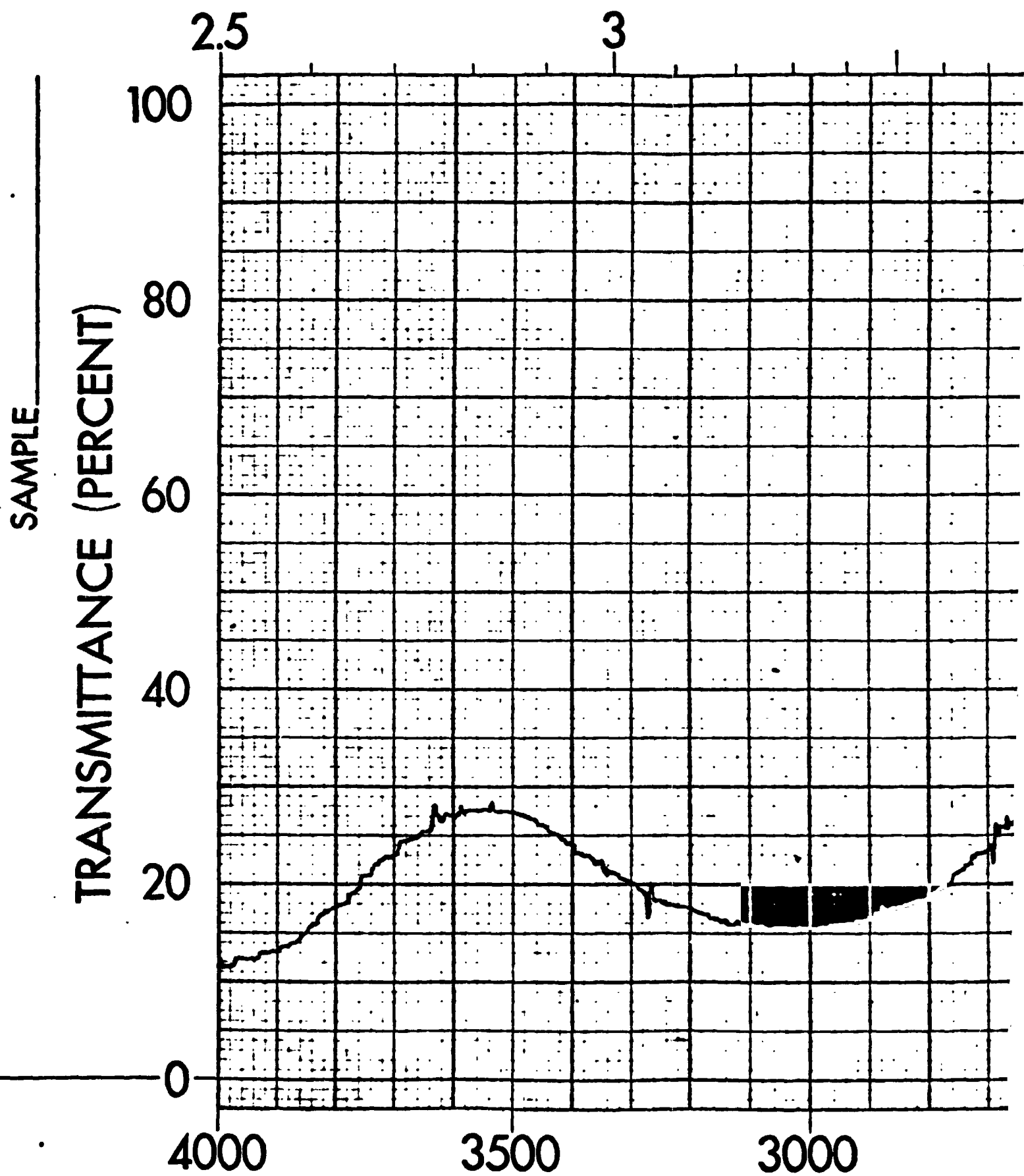
SPECTRUM NO. B-03069
SAMPLE GAS CELL S/N 112
AFTER BEING IN 85° OVEN
ORIGIN WITH N₂ PURGE FOR 400 HRS.

PURITY _____

PHASE _____
THICKNESS _____
1. _____
2. _____
3. _____
DATE 4/9/76
OPERATOR KENNEDY
REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____
SLIT PROGRAM _____
GAIN _____
ATTENUATOR SPEED _____
SCAN TIME _____
SUPPRESSION _____
SCALE EXPANSION _____
SOURCE CURRENT _____

NO. 221-1607



WAVELENGTH (MICRON)

4

5

6

100

100

80

80

60

60

40

40

20

20

0

0

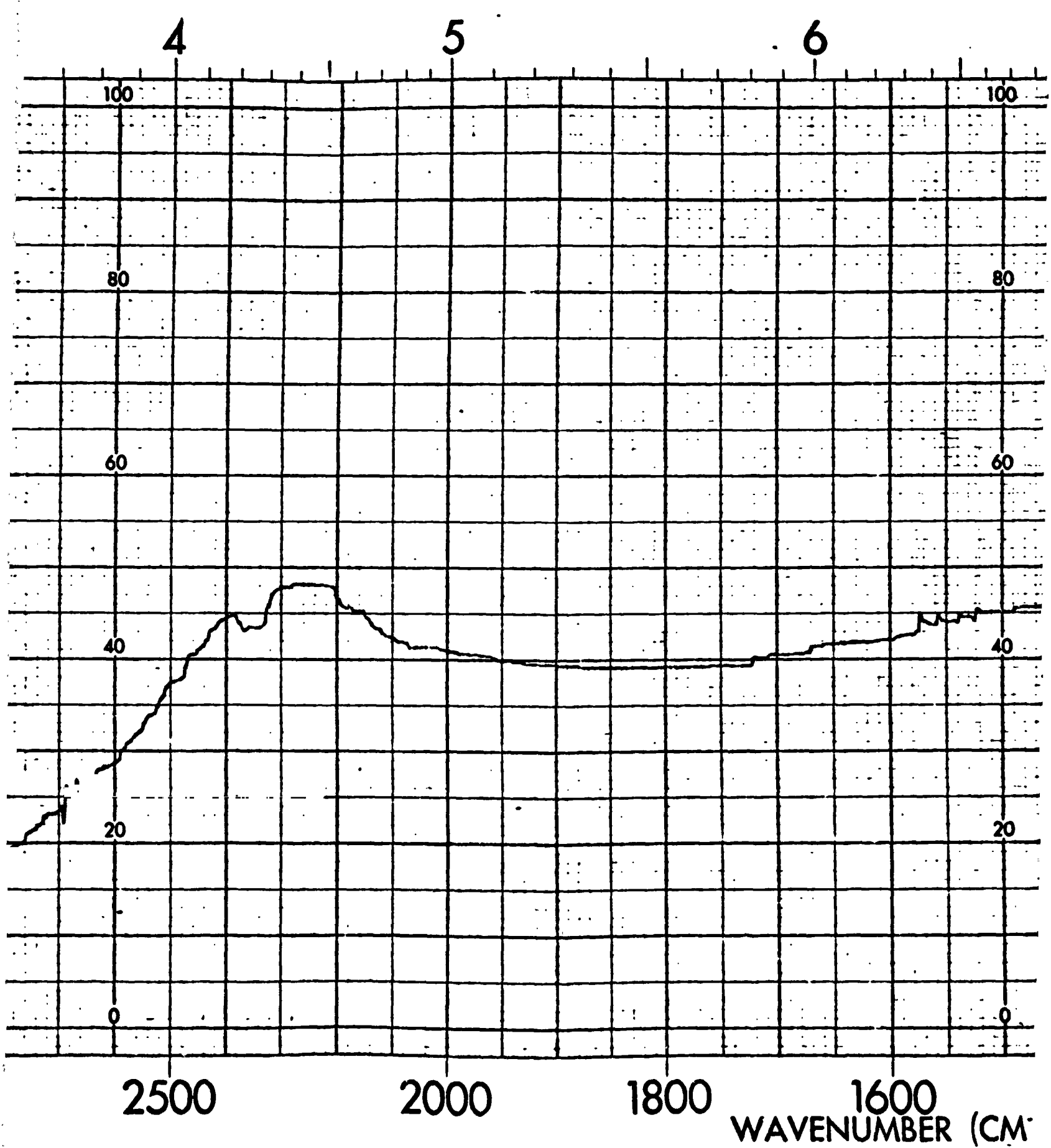
2500

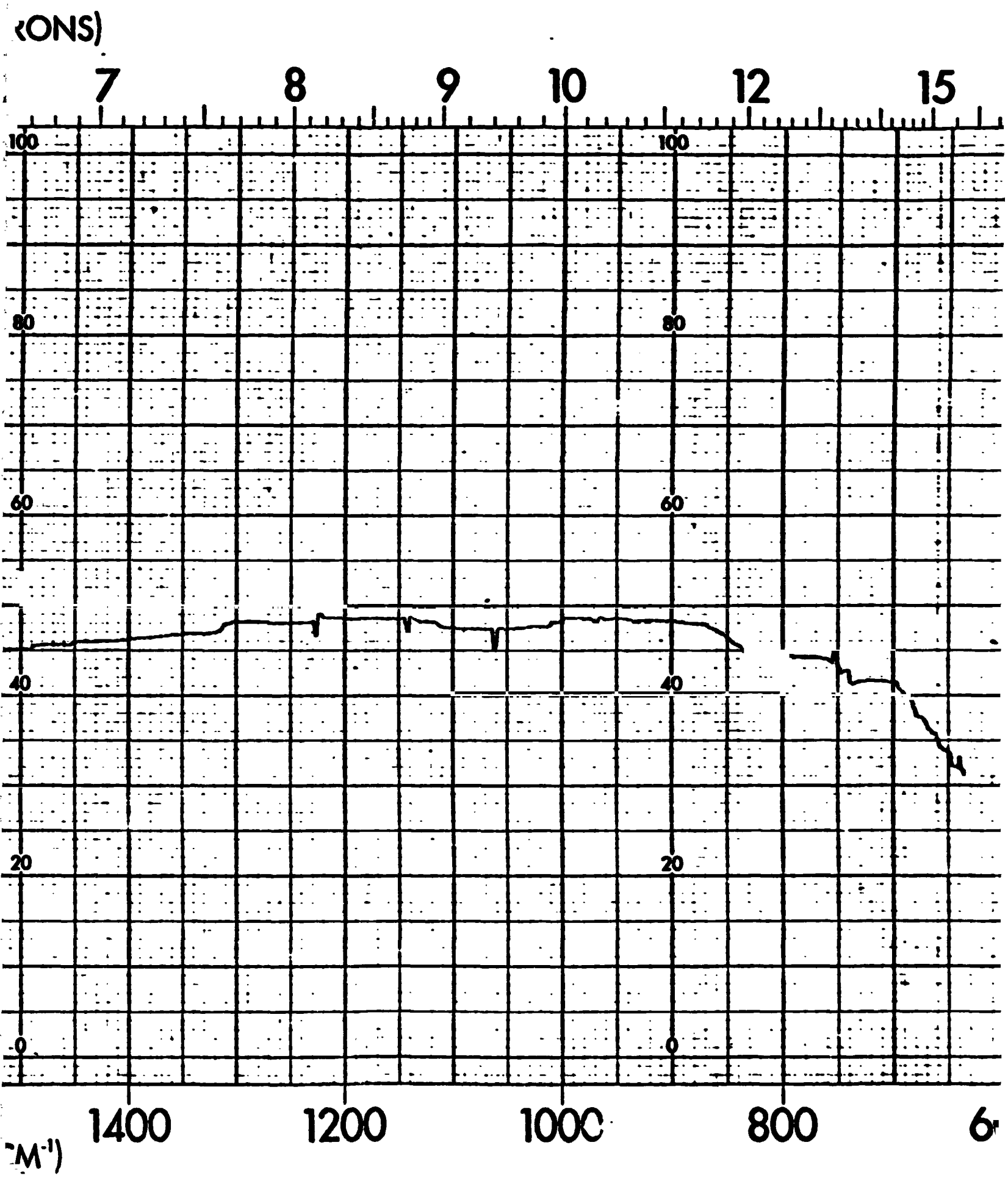
2000

1800

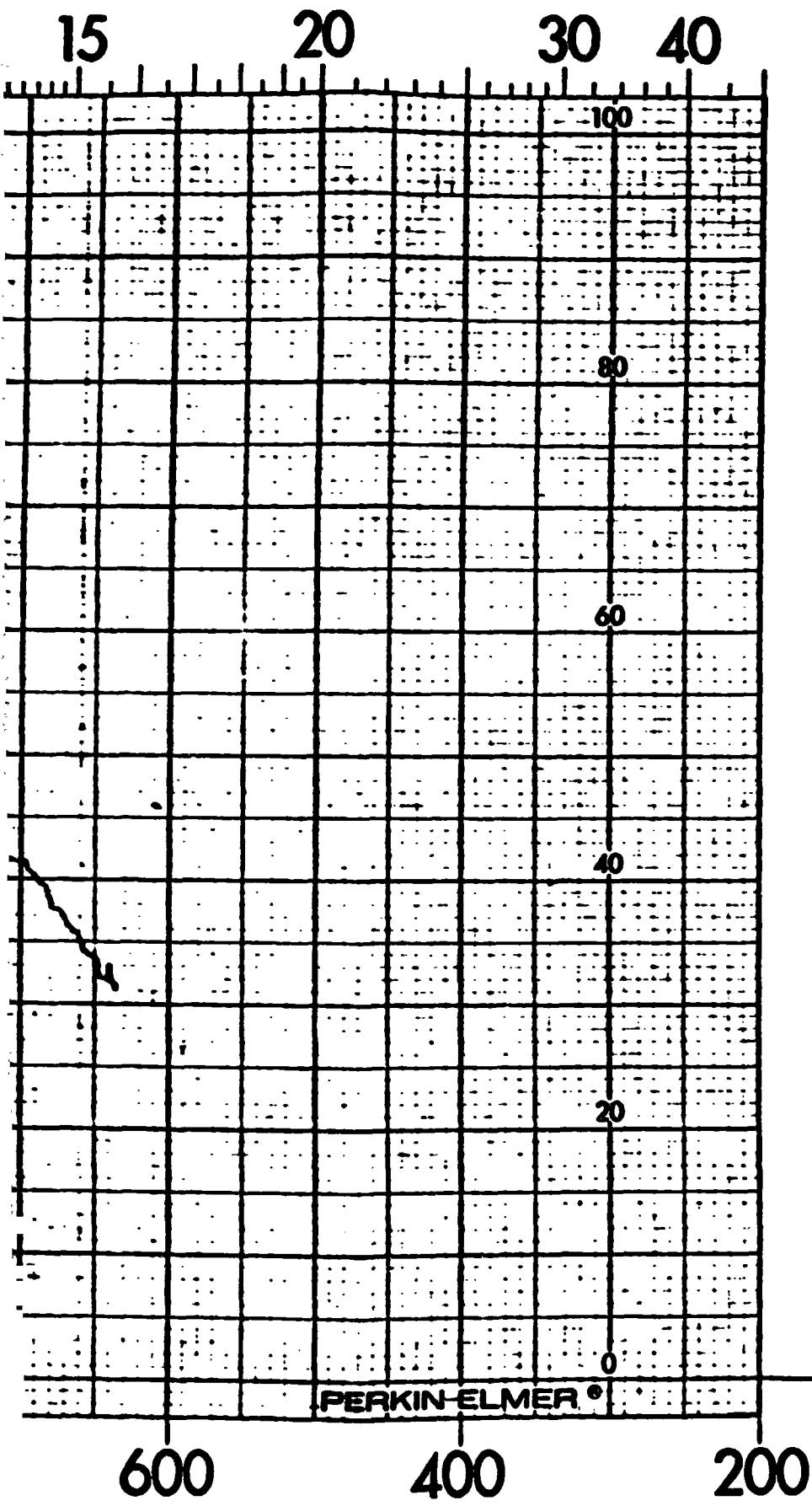
1600

WAVENUMBER (CM⁻¹)





21#



SPECTRUM NO. B-03137

SAMPLE SH 112 After heating
3 hrs. at 110°C

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 4/28/96

OPFRATOR _____

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

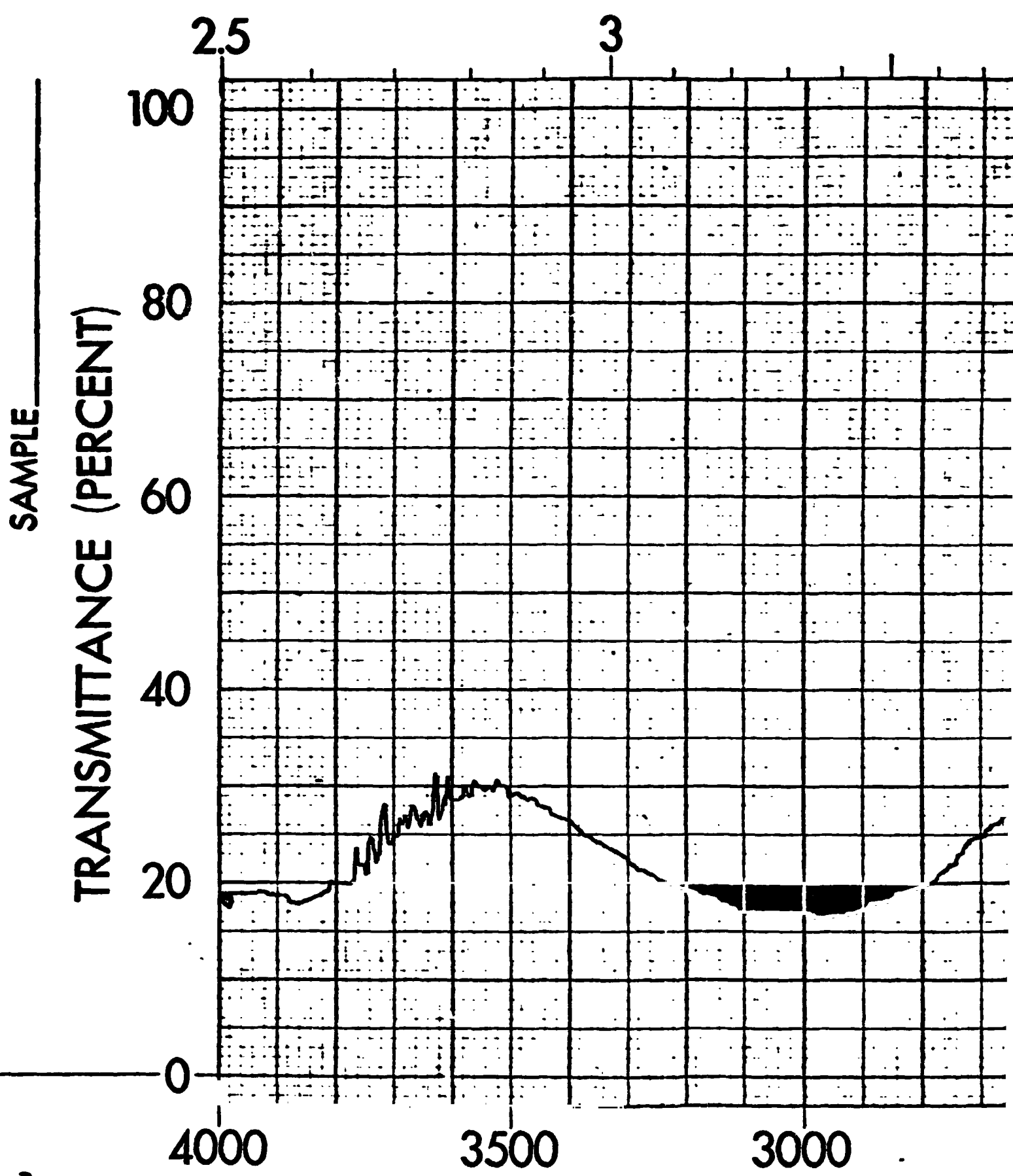
SUPPRESSION _____

SCALE EXPANSION _____

SOURCE CURRENT _____

NO. 221-1607

#5

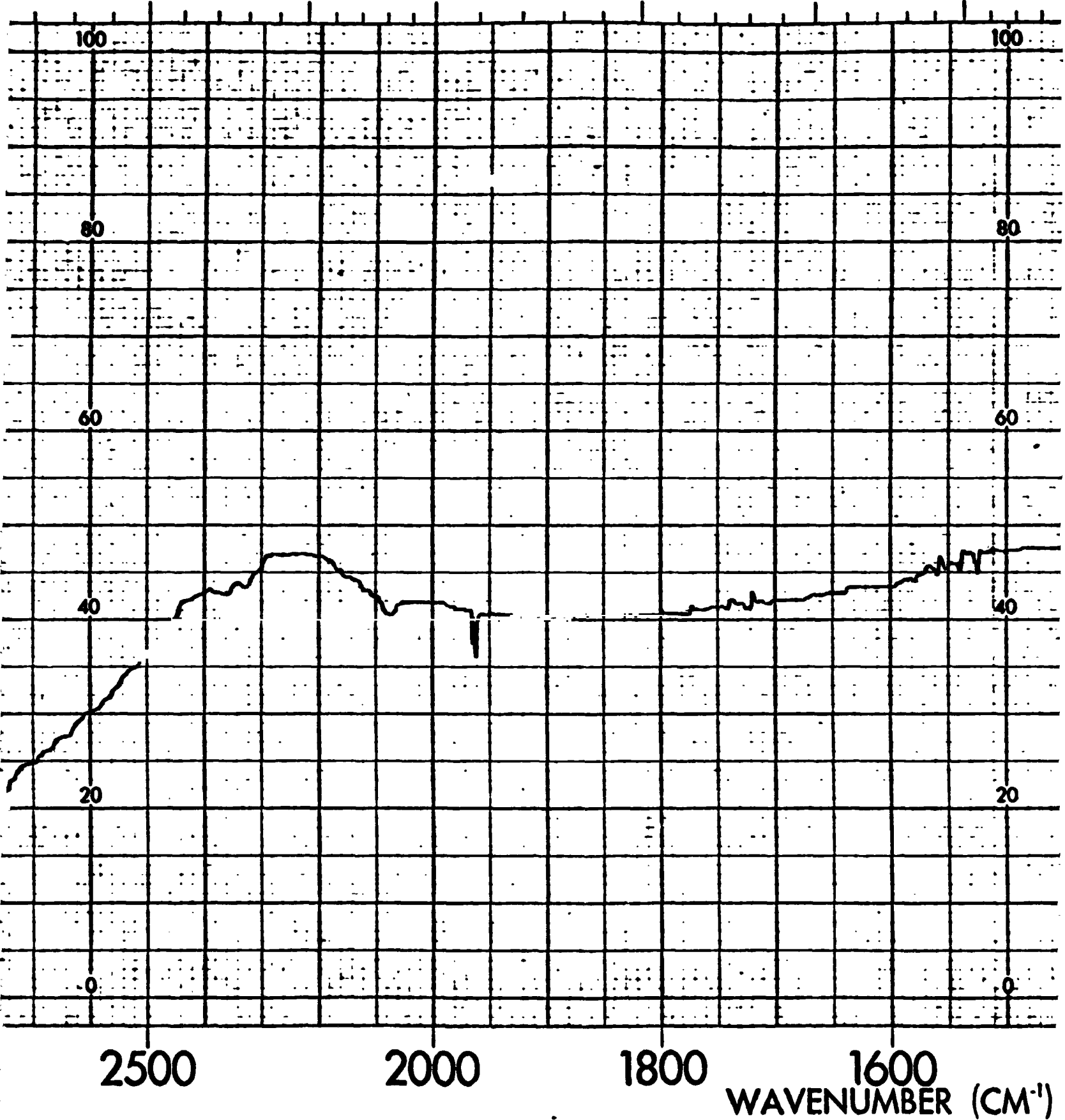


WAVELENGTH (MICRON)

4

5

6



CRONS)

7

8

9

10

12

15

100

100

80

80

60

60

40

40

20

20

0

0

INSTRUMENTAL
NOISE

INSTRUMENTAL
NOISE
40

1400

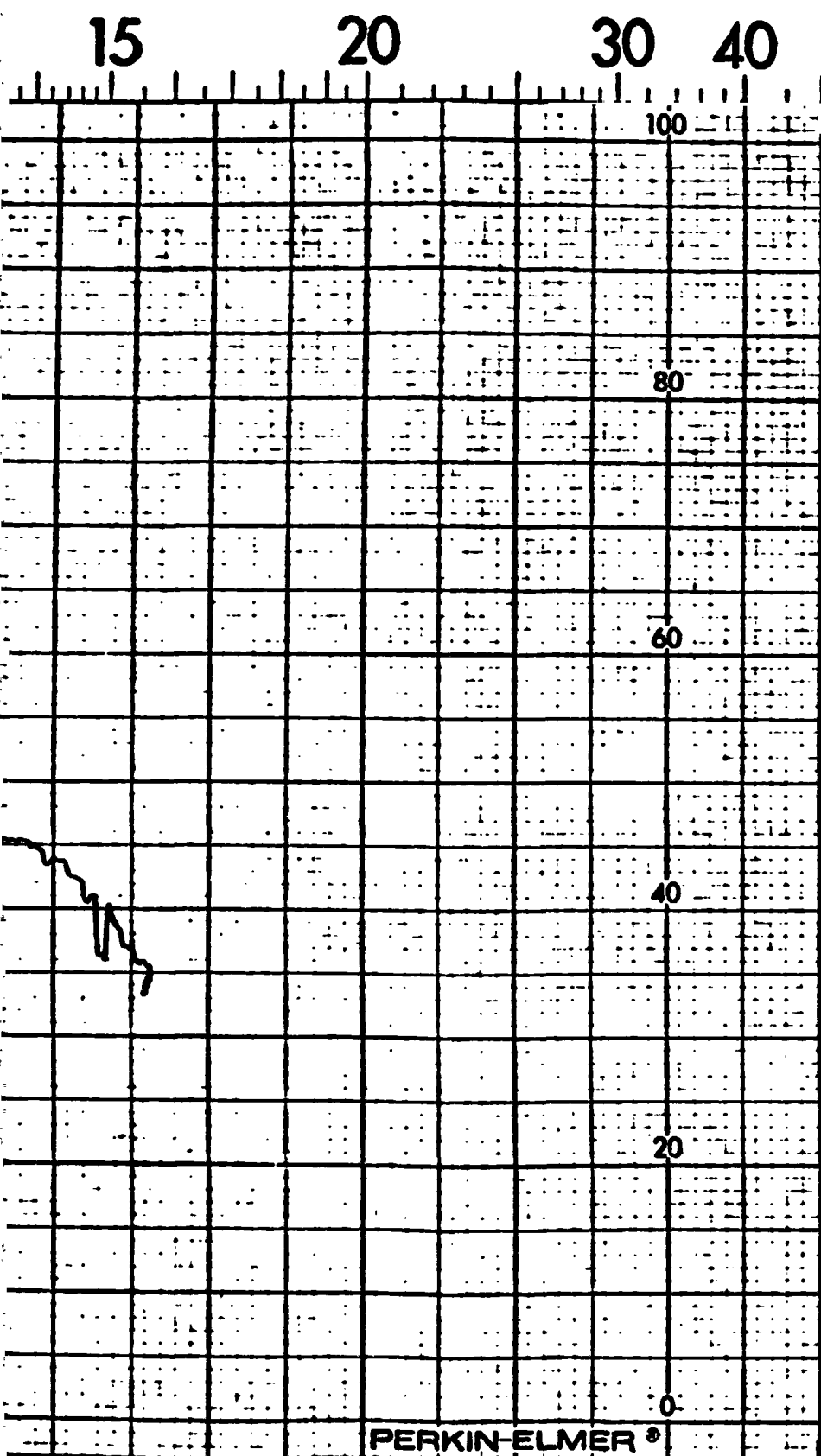
1200

1000

800

ϵ

CM⁻¹)



SPECTRUM NO. B-03161

SAMPLE GAS CELL S/N 112

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS CELL EXPOSED TO

1. NH₃ IN 70°C OVEN FOR 4 HR.

2. _____

3. _____

DATE 5/3/76

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION 1X

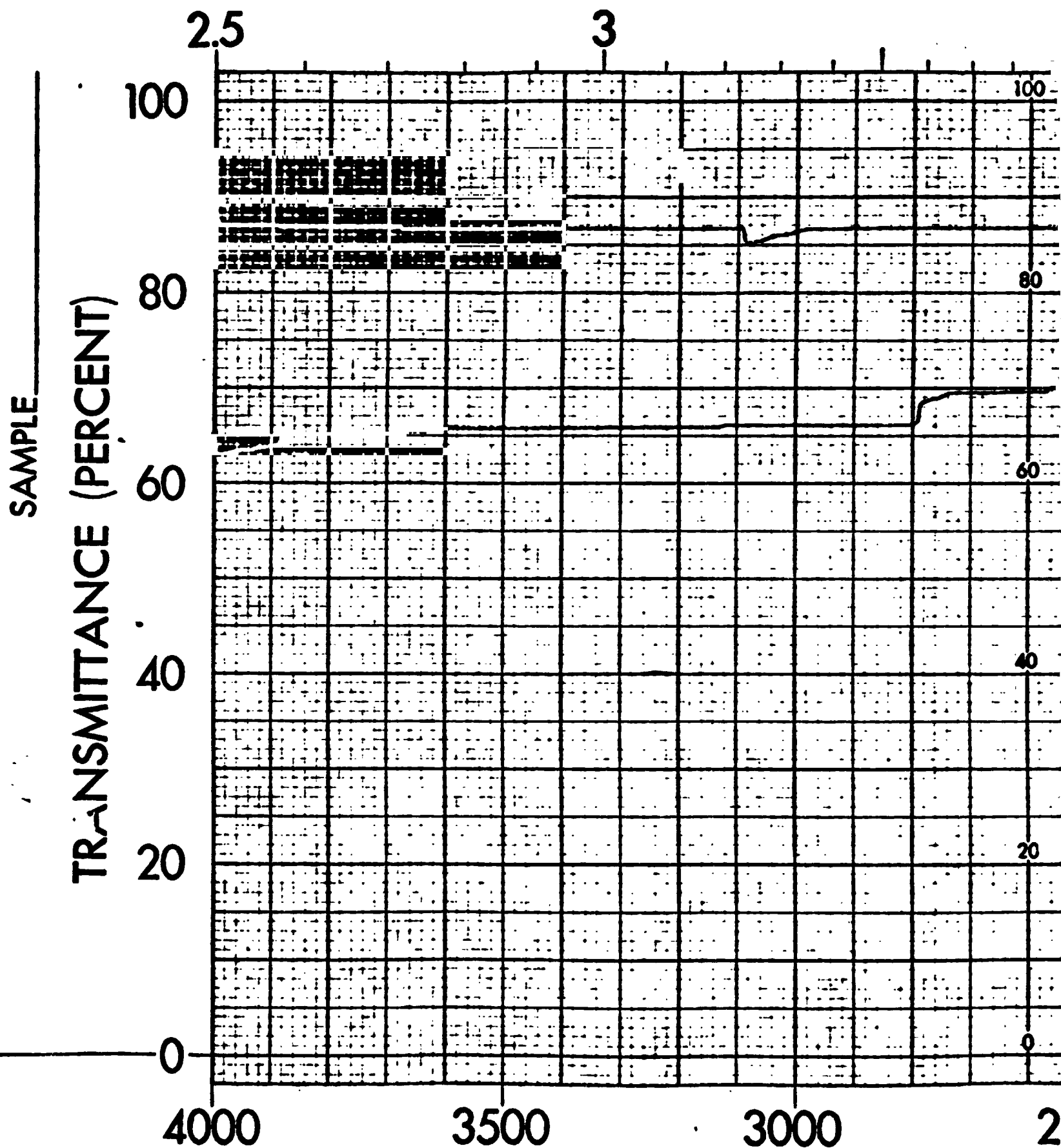
SOURCE CURRENT _____

600

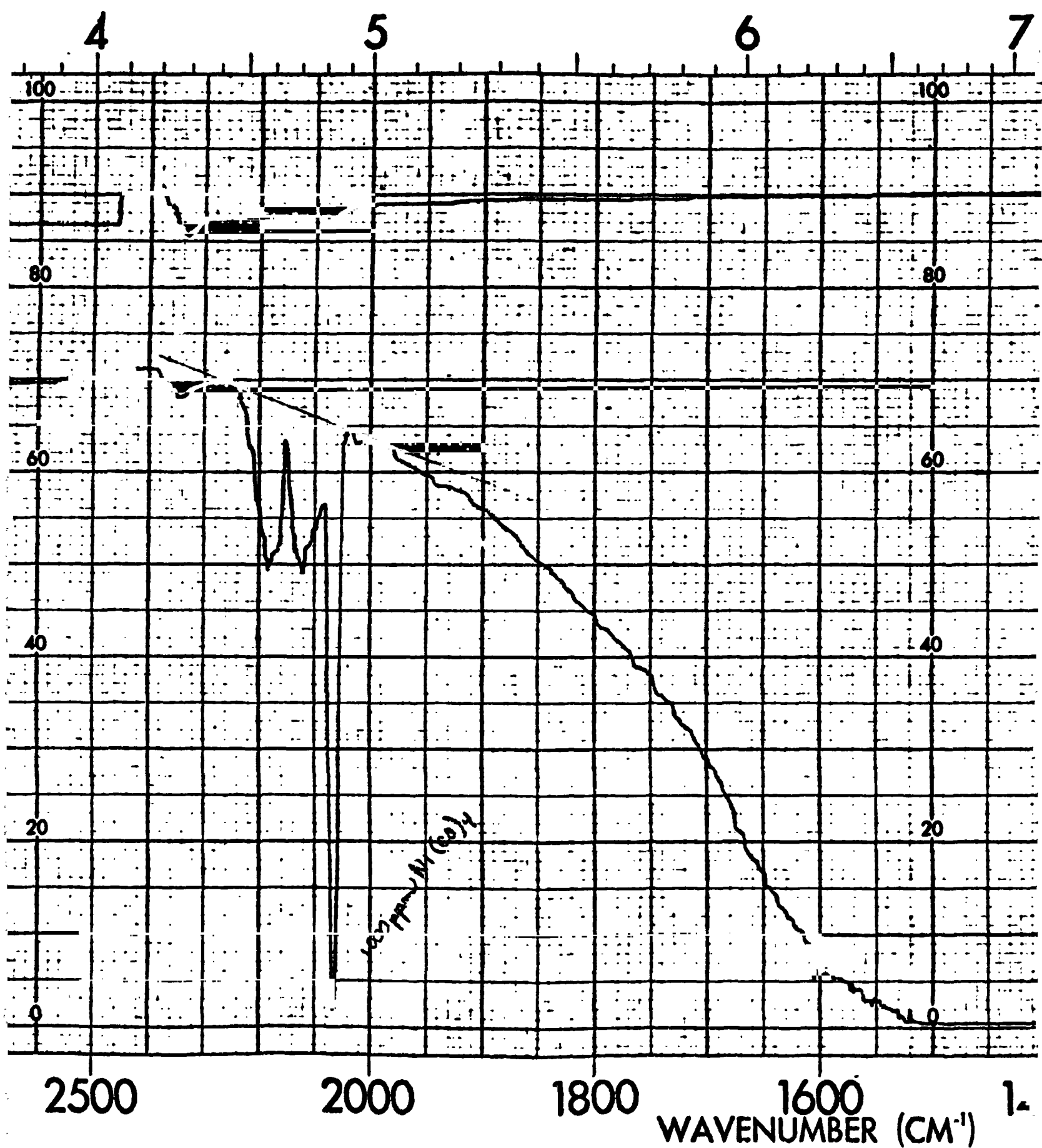
400

200

NO. 221-1607



WAVELENGTH (MICRONS)



11CRONS)

7

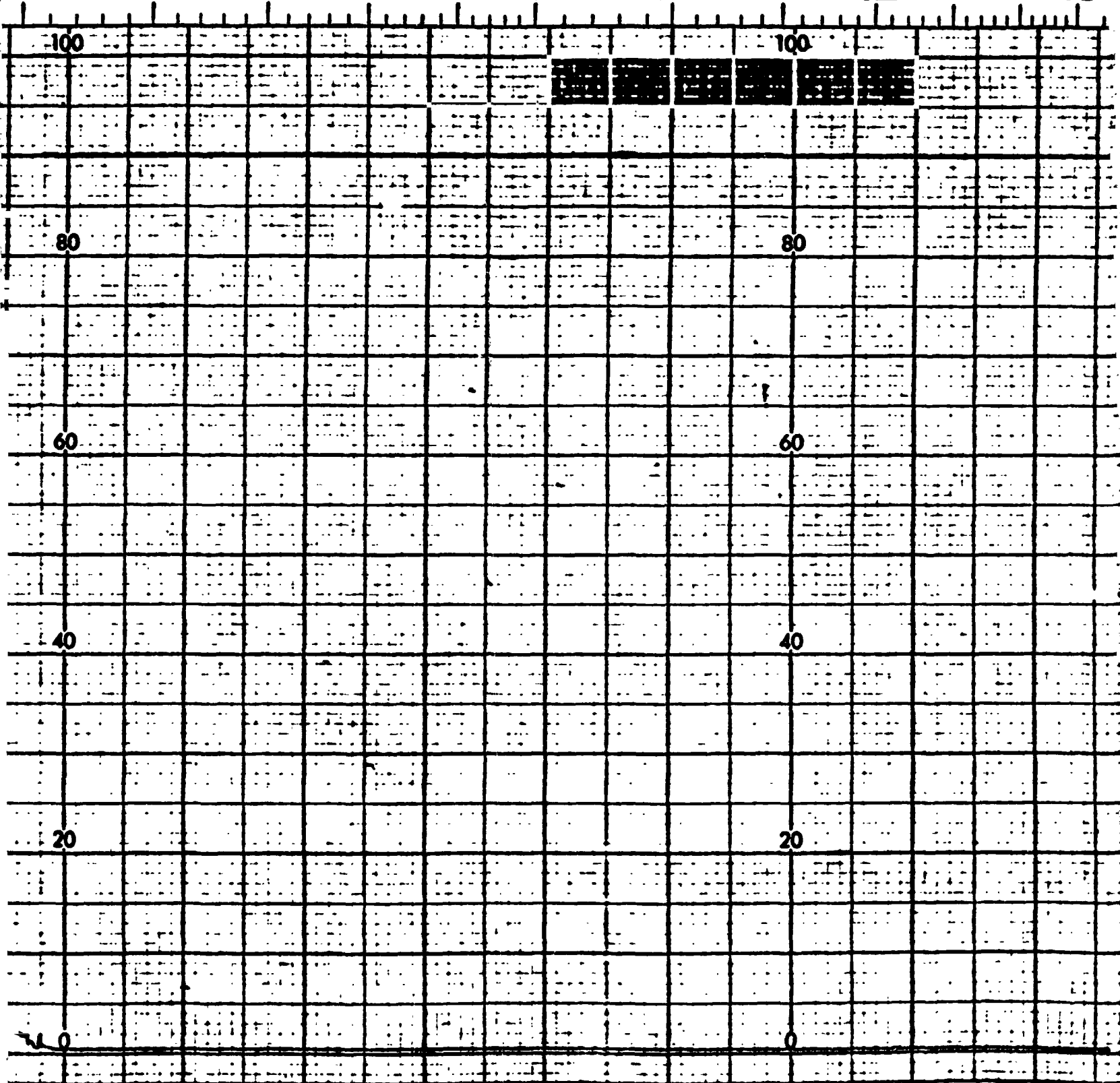
8

9

10

12

15



(CM⁻¹)

1400

1200

1000

800

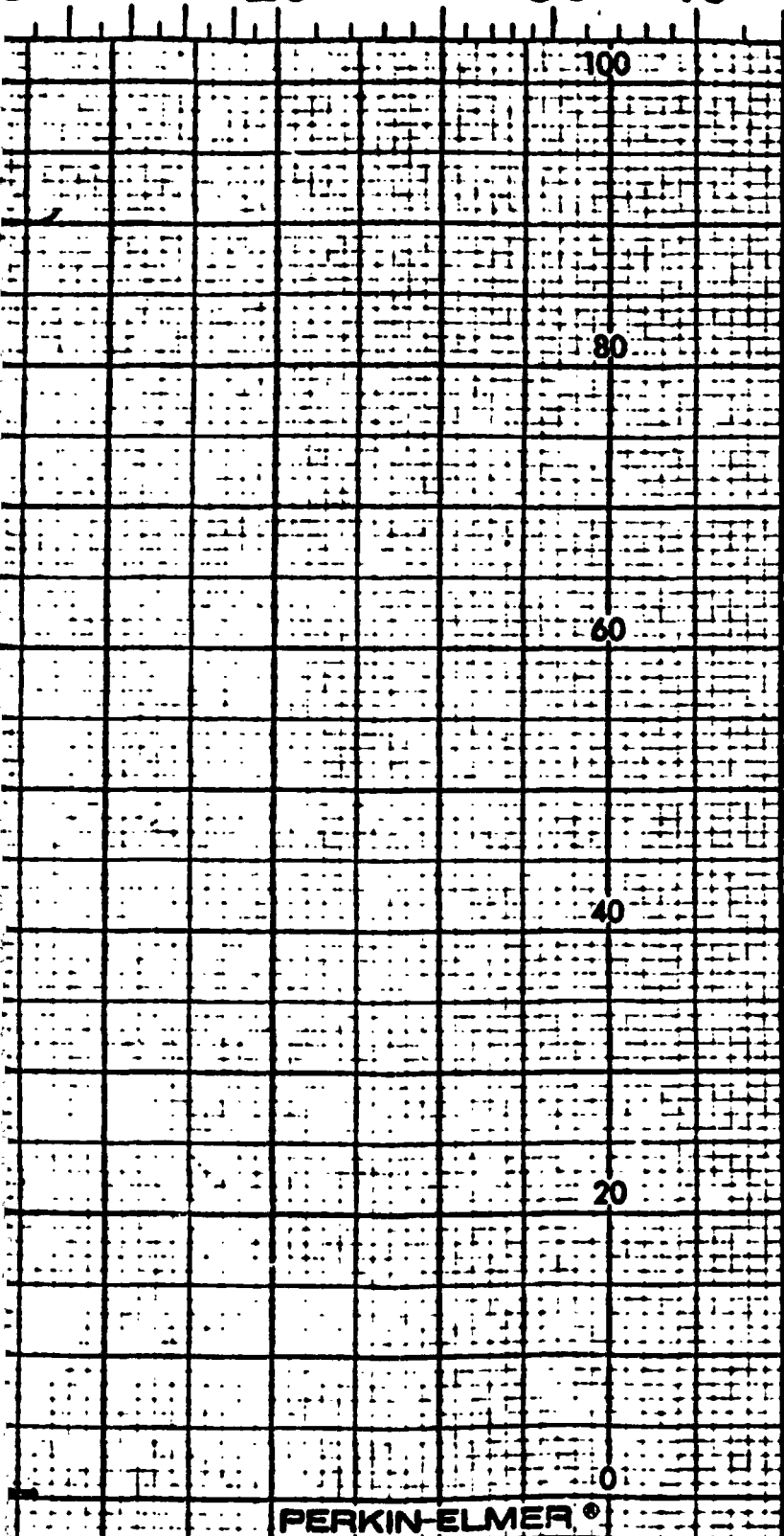
FOLDOUT FRAME 3

71*

20

30

40



PERKIN-ELMER®

600

400

200

SPECTRUM NO. B-03073

SAMPLE GAS CELL S/N 101

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 4/12/76

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

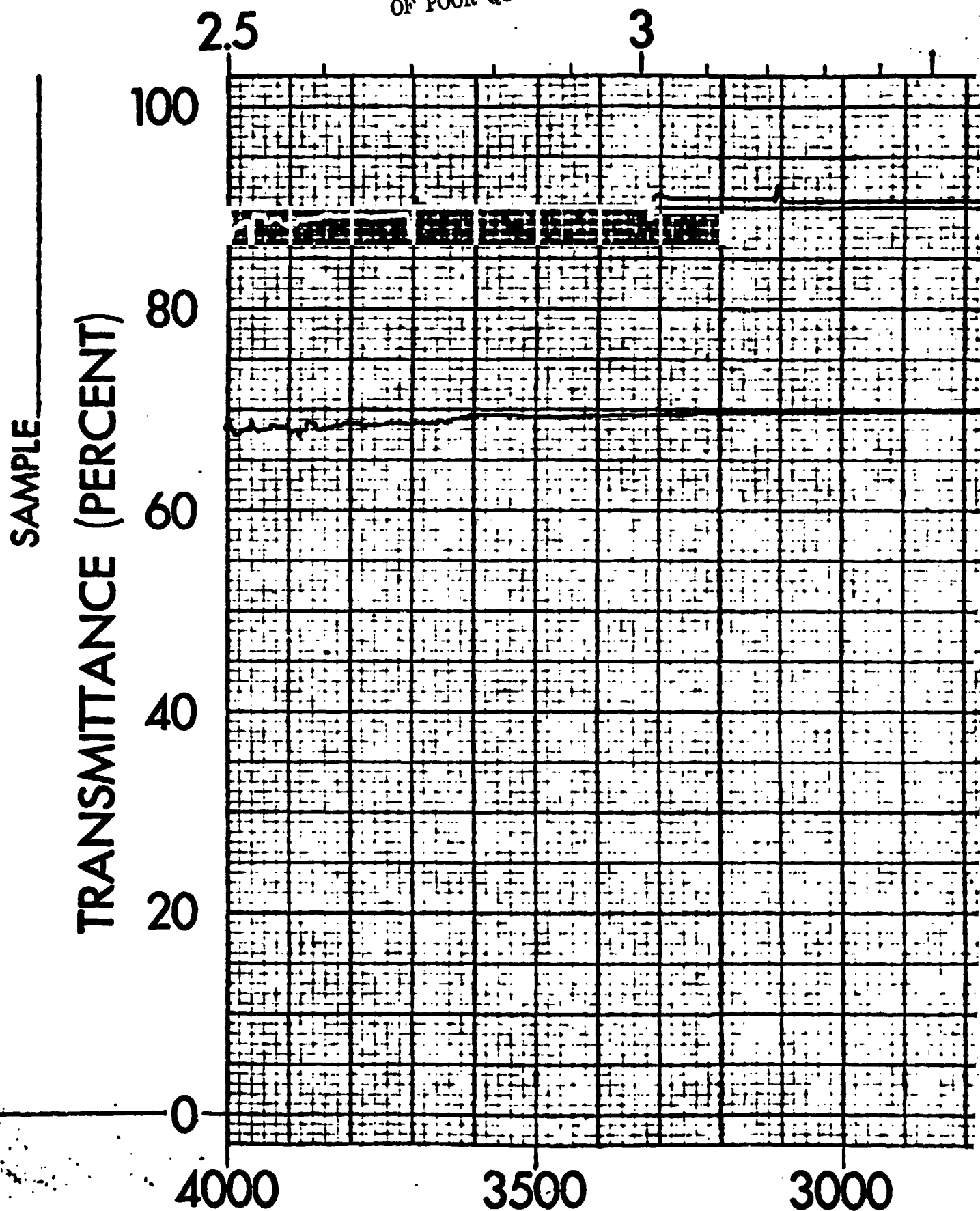
SCALE EXPANSION _____

SOURCE CURRENT _____

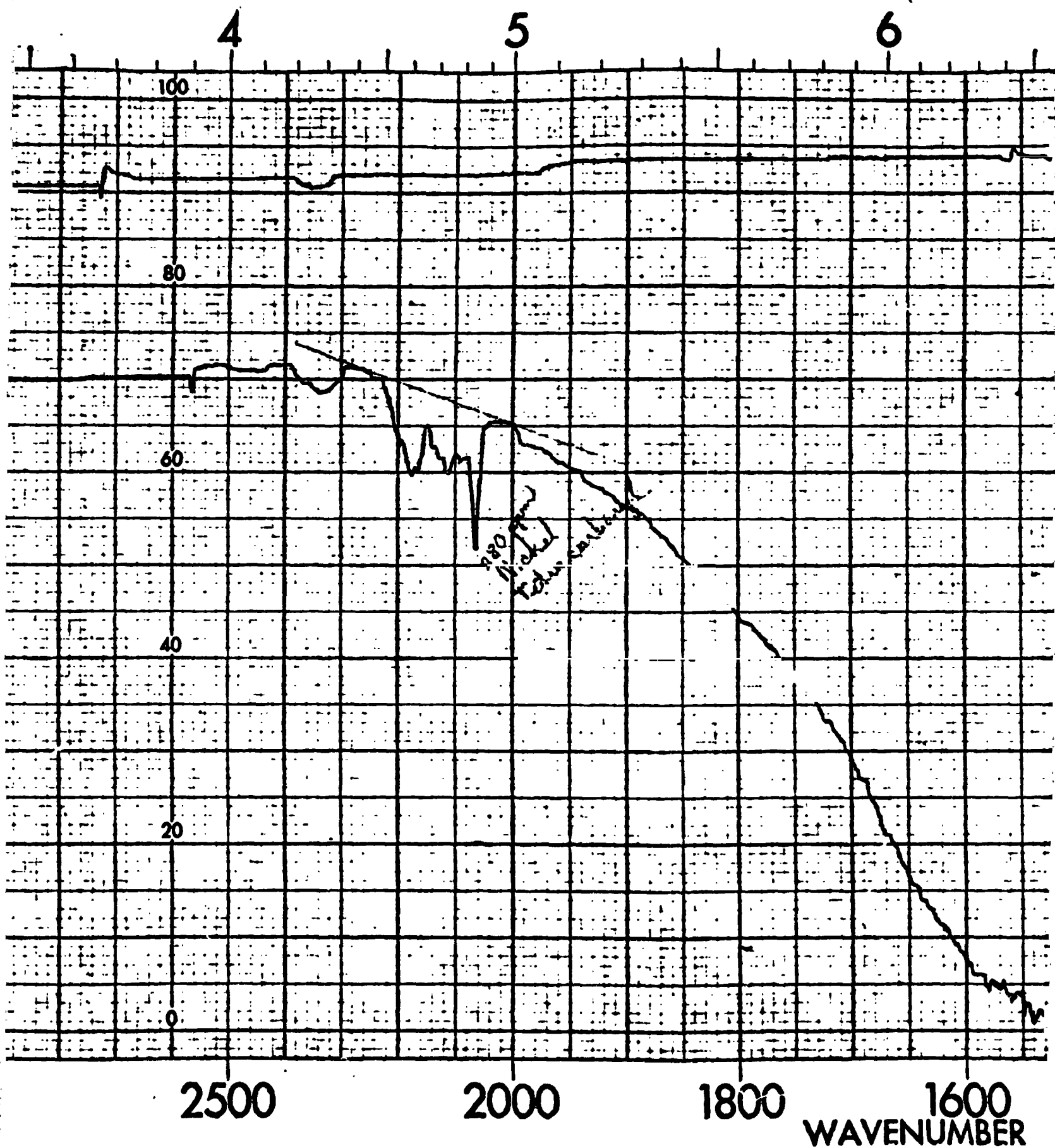
NO. 221-1607

81#

ORIGINAL PAGE IS
OF POOR QUALITY



WAVELENGTH (MIC



(MICRONS)

7

8

9

10

12

100

100

80

80

60

60

40

40

20

20

0

0

WAVE
NUMBER (CM⁻¹)

1400

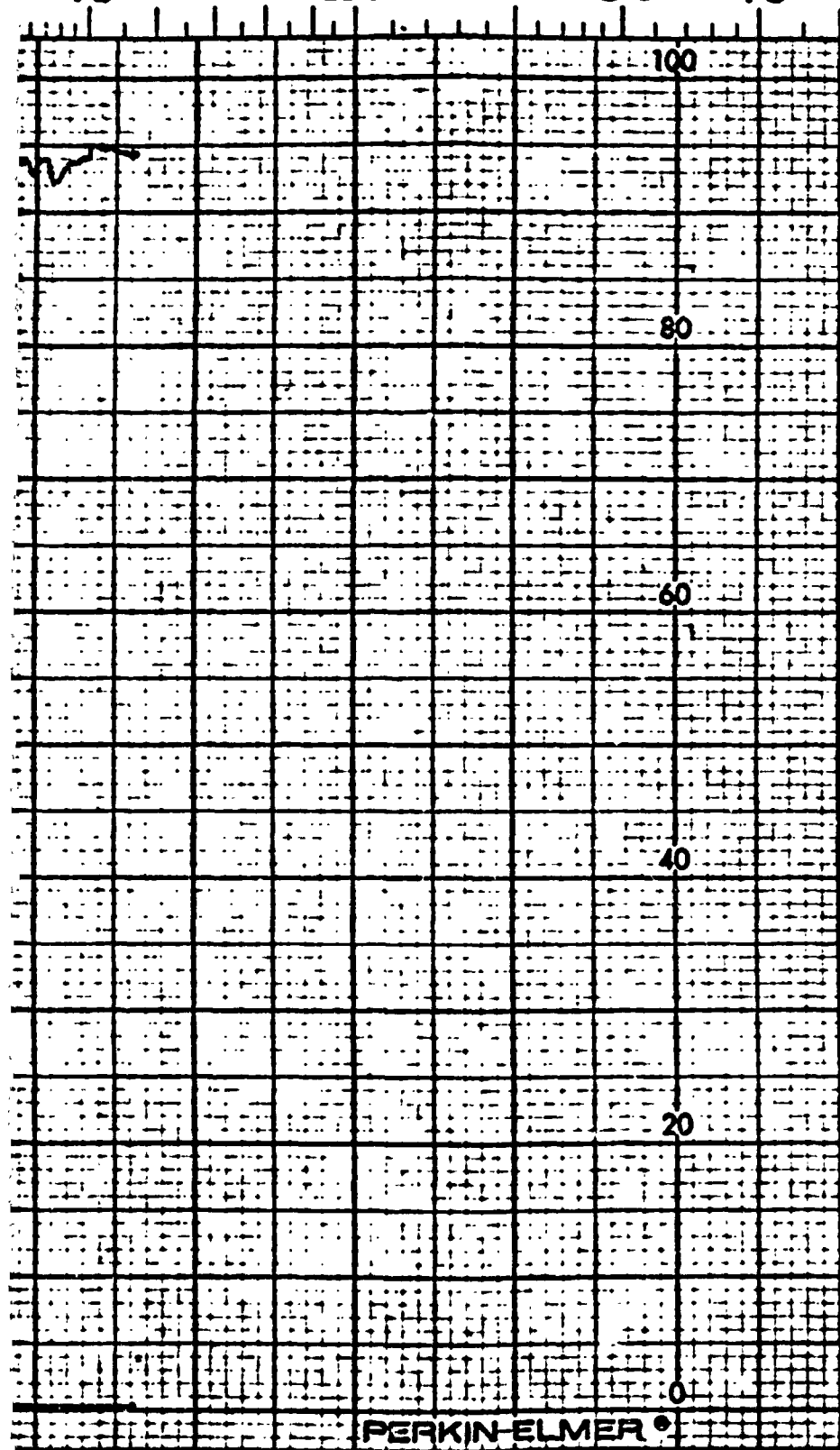
1200

1000

800

FOLDOUT FRAME 3

15 20 30 40



SPECTRUM NO. B-03074

SAMPLE GAS CELL S/N 102

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 4/12/76

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION _____

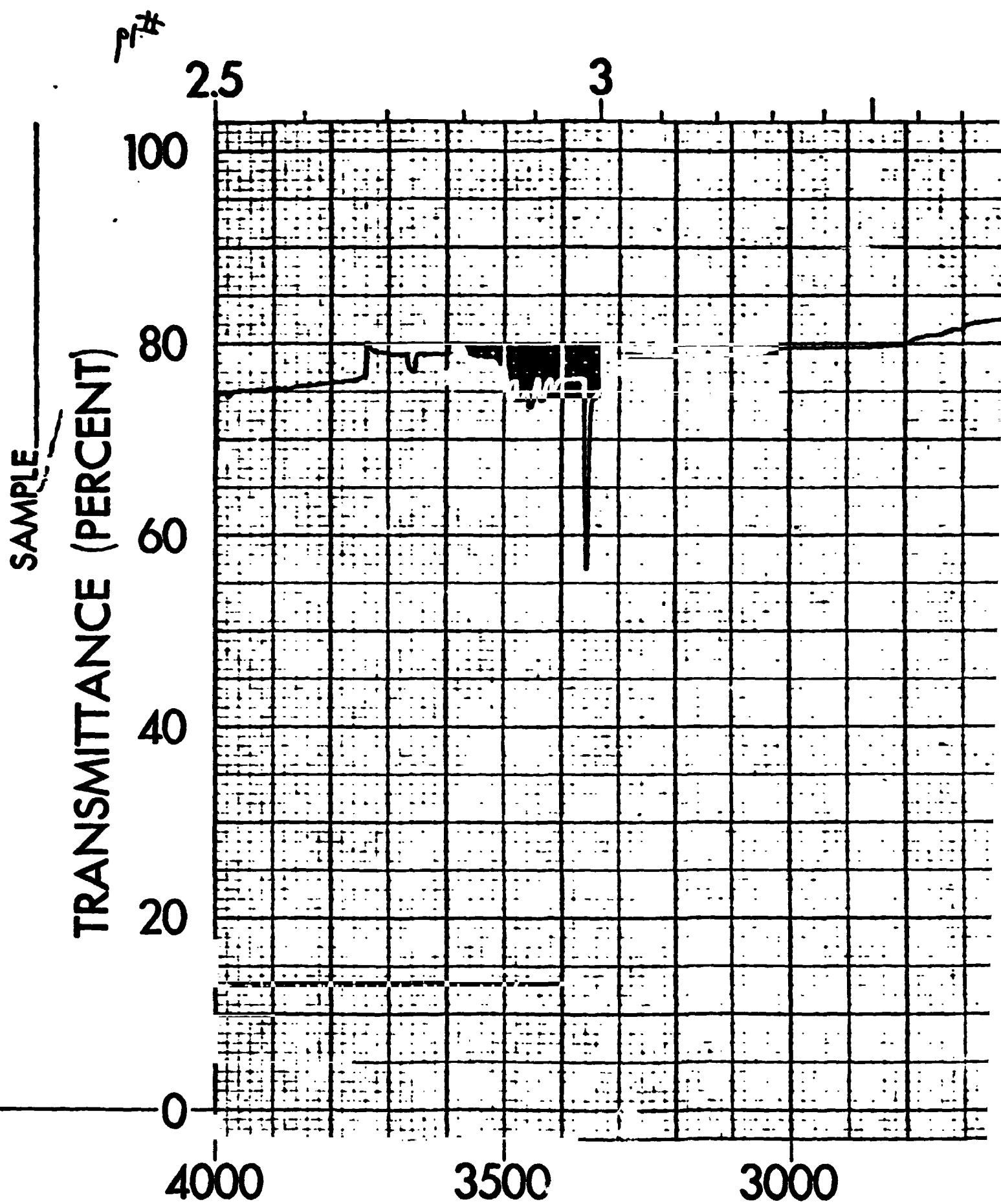
SOURCE CURRENT _____

600

400

200

NO. 221-1607

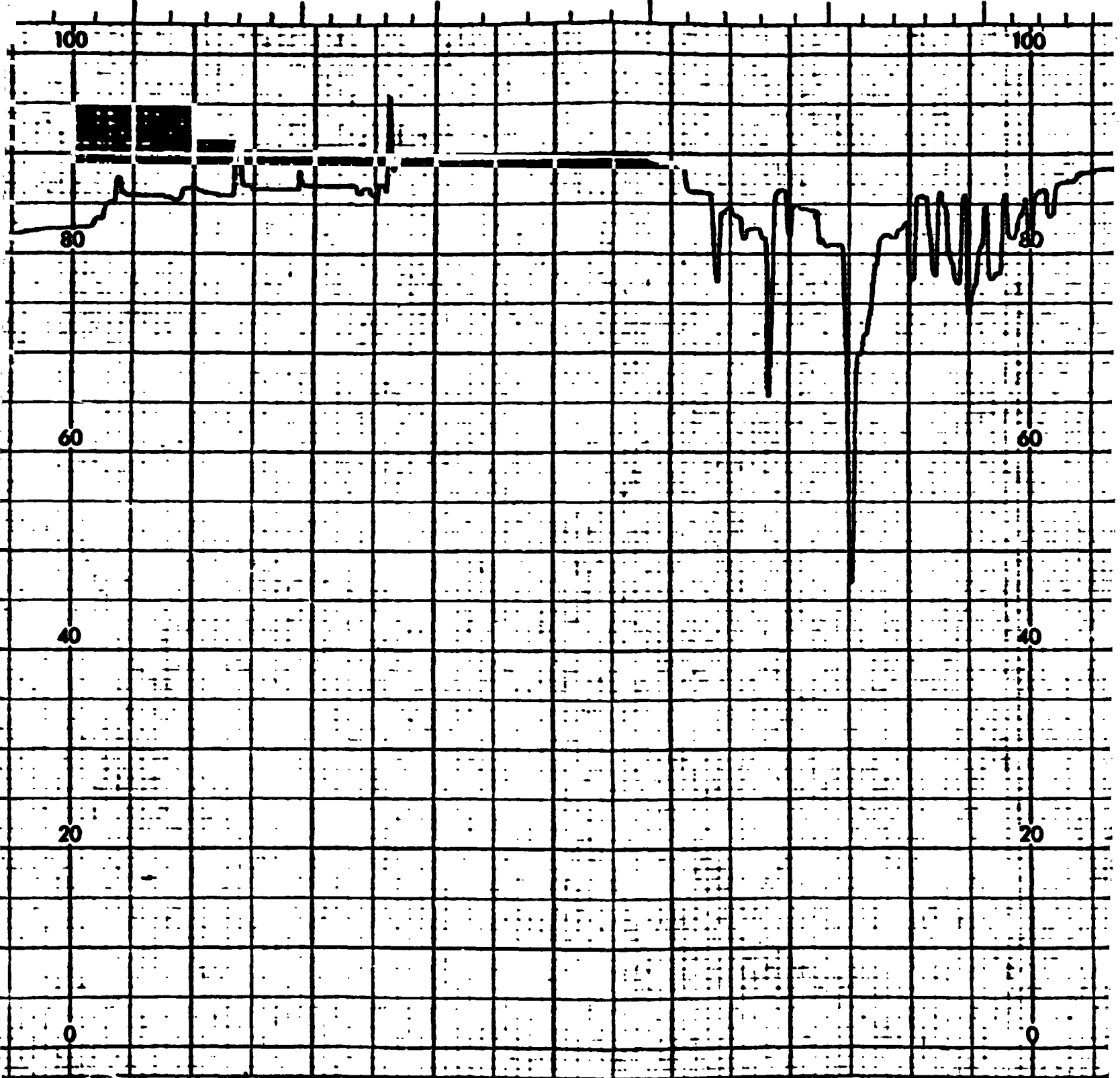


WAVELENGTH (MICRONS)

4

5

6



2500

2000

1800

1600

WAVENUMBER (CM⁻¹)

ONS)

7

8

9

10

12

15

100

80

60

40

20

1400

1200

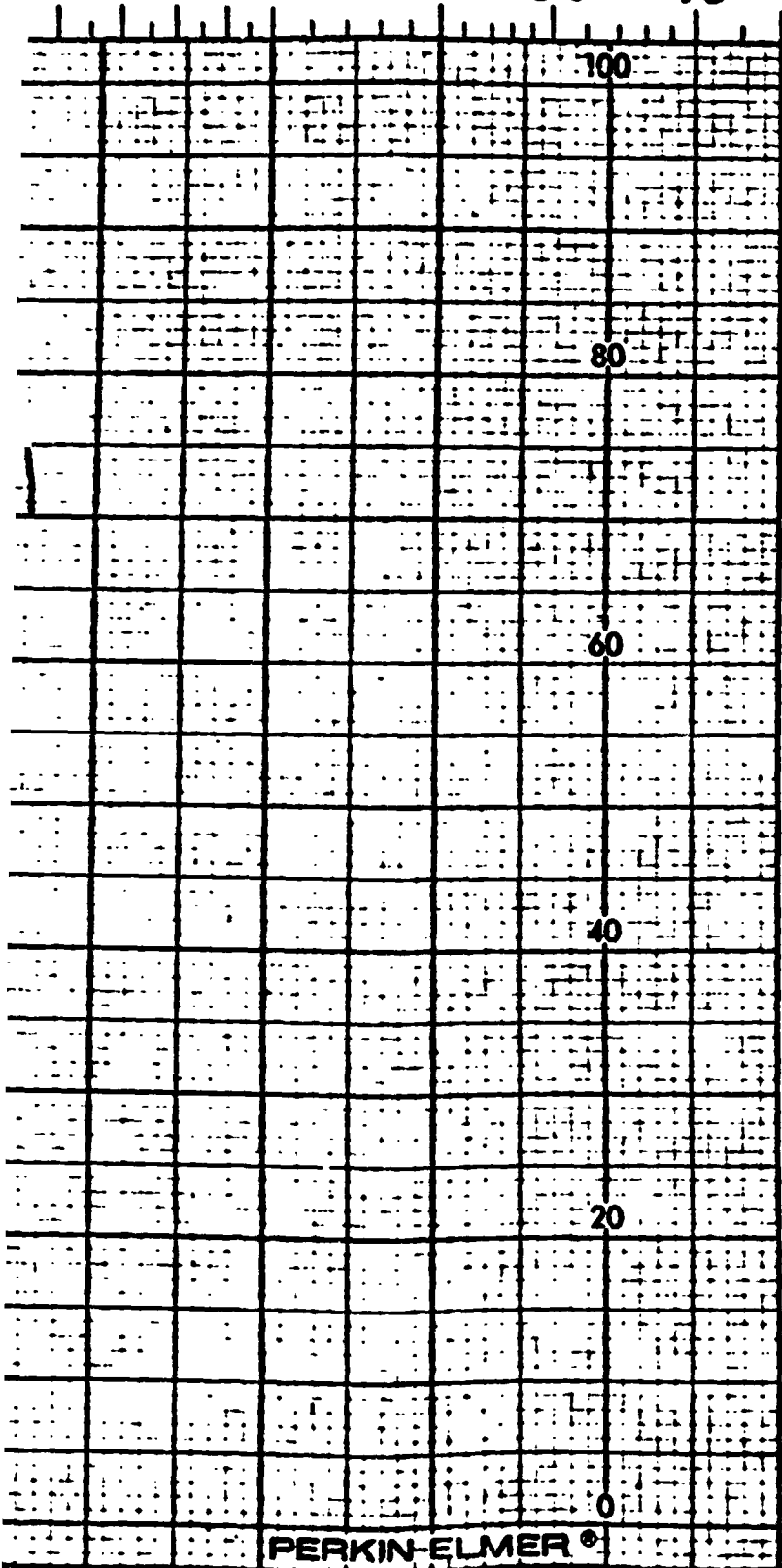
1000

800

600

M⁻¹)

20 30 40



SPECTRUM NO. B-03215

SAMPLE 5 cm GAS CELL
WITH NH₃

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 5/17/76

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION 1X

SOURCE CURRENT _____

600

400

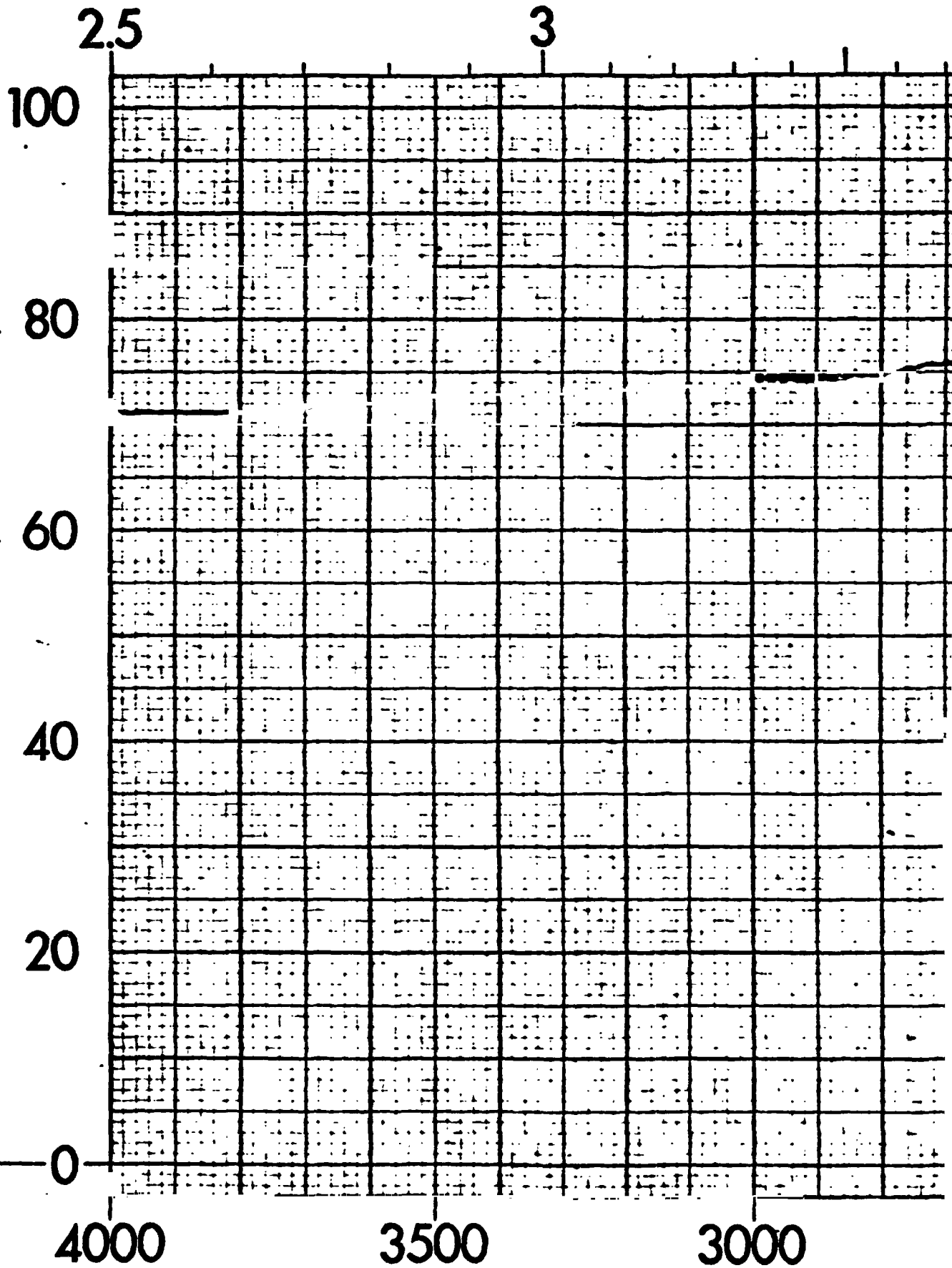
200

NO. 221-1607

02#

SAMPLE

TRANSMITTANCE (PERCENT)

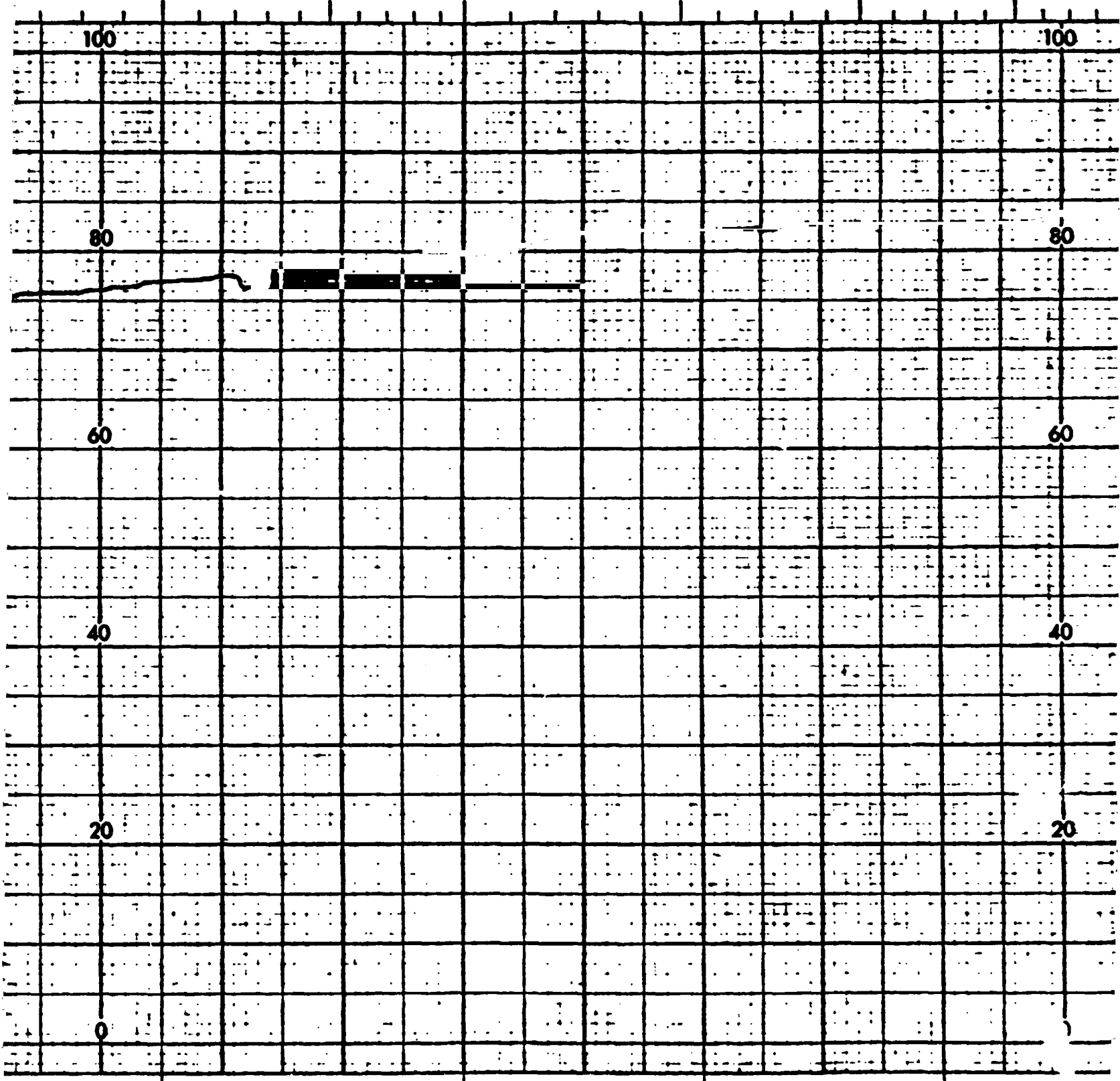


WAVELENGTH (MICRON)

4

5

6



2500

2000

1800

1600

WAVENUMBER (CM⁻¹)

CRONS)

7

8

9

10

12

15

100

100

80

80

60

60

40

40

20

20

0

0

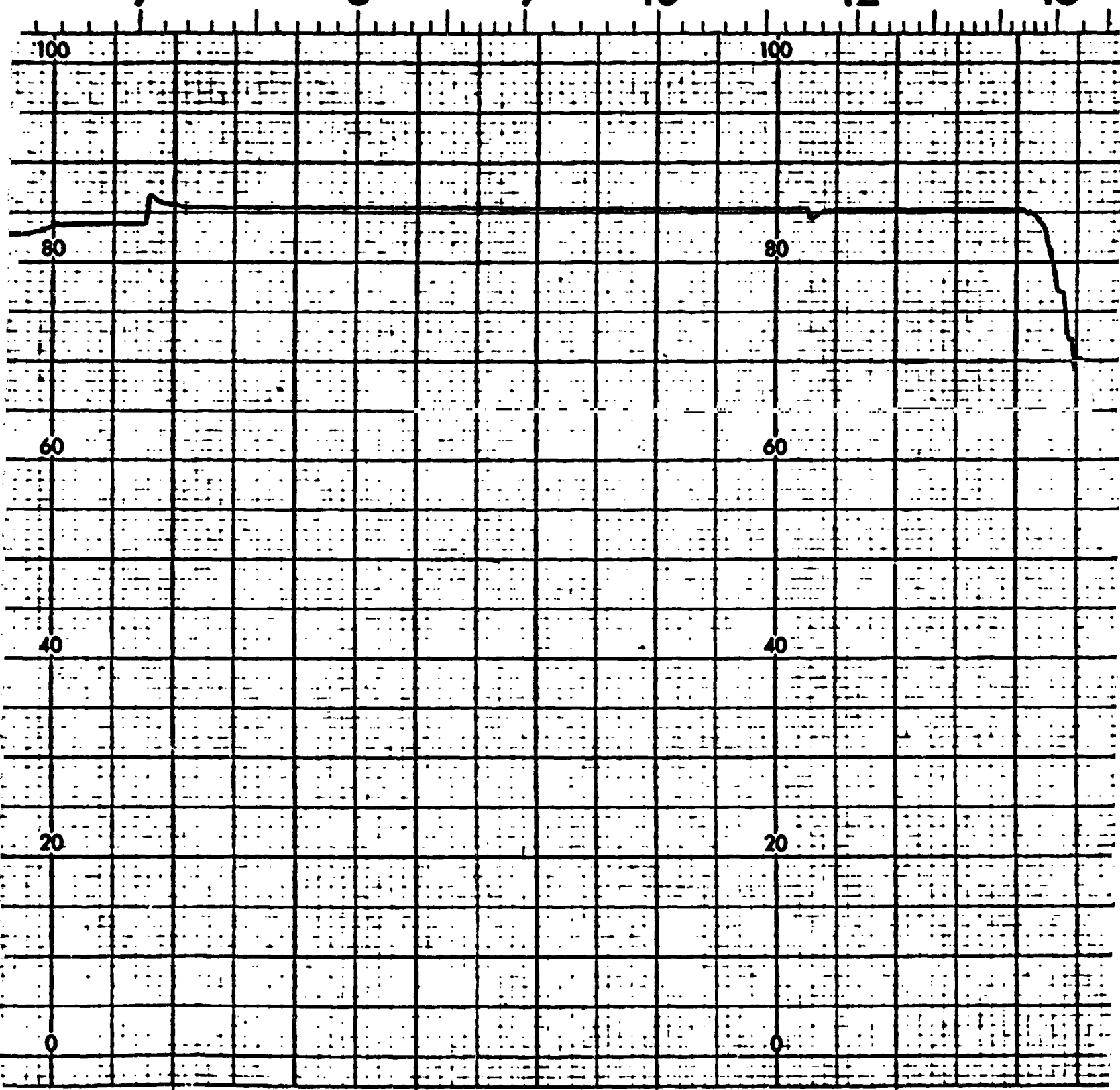
1400

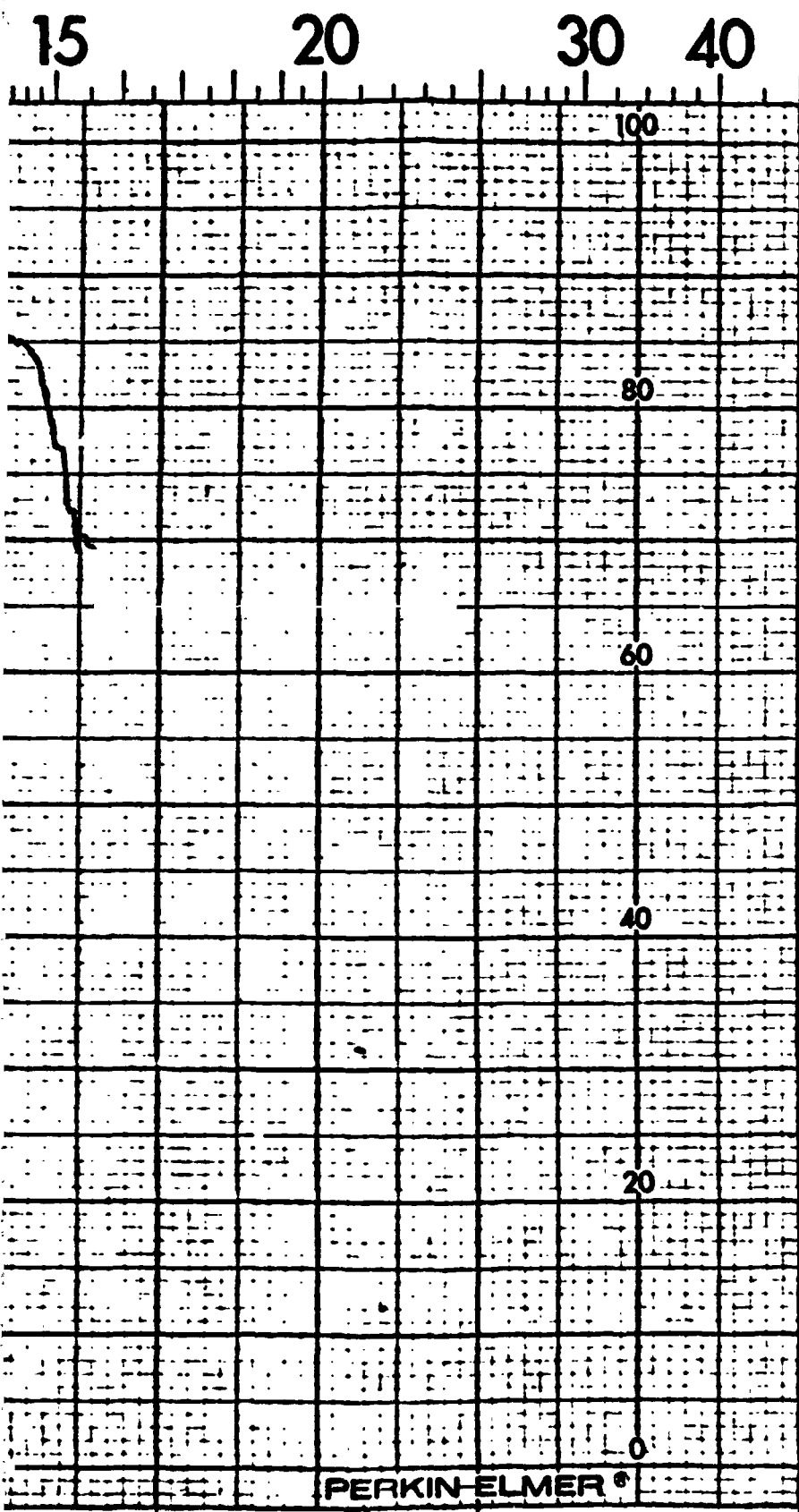
1200

1000

800

(CM⁻¹)





SPECTRUM NO. B-03217
SAMPLE 5 cm. Gas Cell with NH₃
AFTER BEING IN 15°C oven for
ORIGIN 2A WRS
PURITY _____
PHASE _____
THICKNESS _____
1. _____
2. _____
3. _____
DATE 5/18/76
OPERATOR KENNEDY
REMARKS _____
MODEL 521 2:1 SCALE CHANGE _____
SLIT PROGRAM _____
GAIN _____
ATTENUATOR SPEED _____
SCAN TIME _____
SUPPRESSION _____
SCALE EXPANSION 1x
SOURCE CURRENT _____

600

400

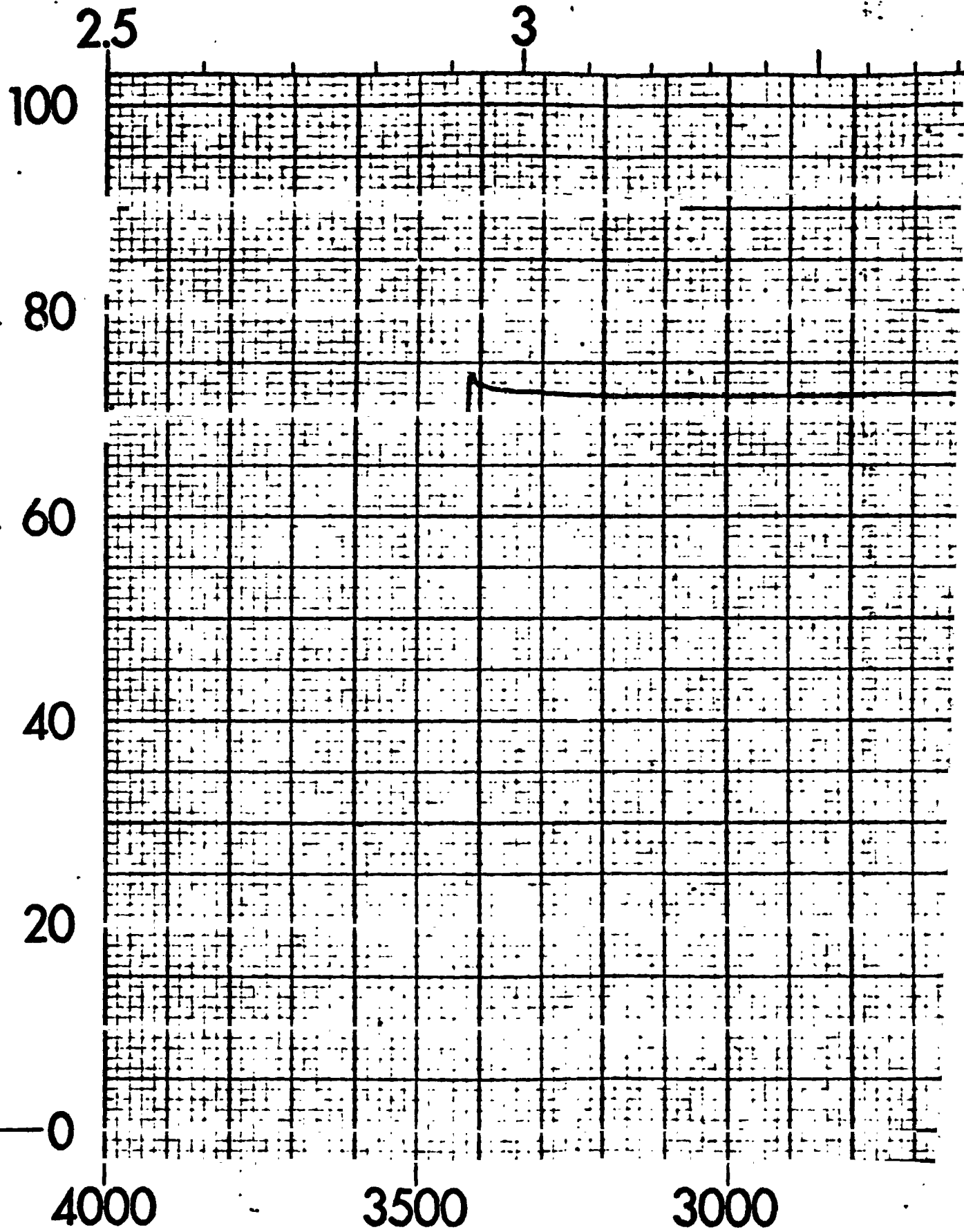
200

NO. 221-1607

121

SAMPLE

TRANSMITTANCE (PERCENT)



WAVELENGTH (MICRONS)

4

5

6

7

100

100

80

80

60

60

40

40

20

20

0

0

2500

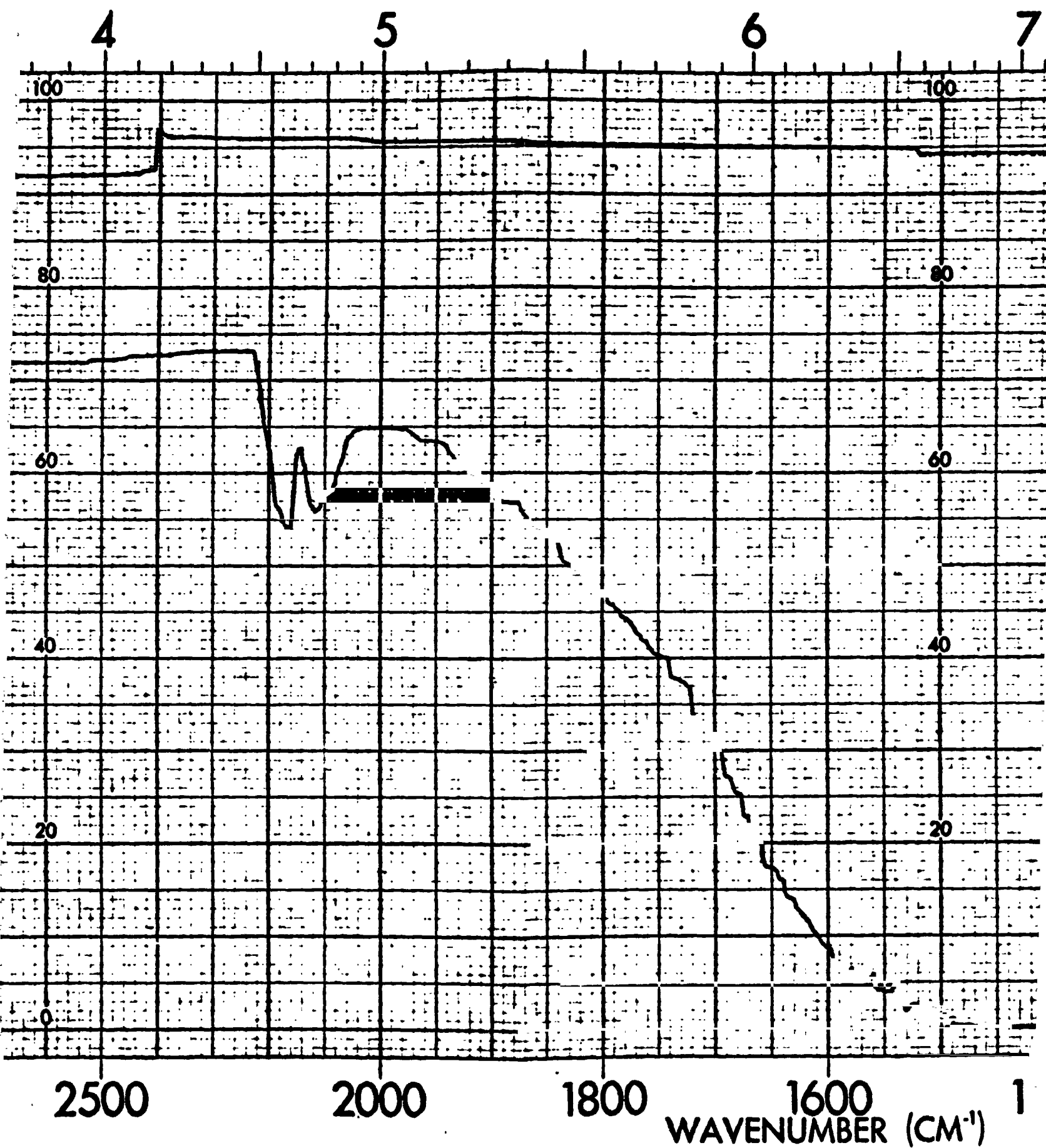
2000

1800

1600

1

WAVENUMBER (CM⁻¹)



3)

7

8

9

10

12

15

100

80

60

40

20

0

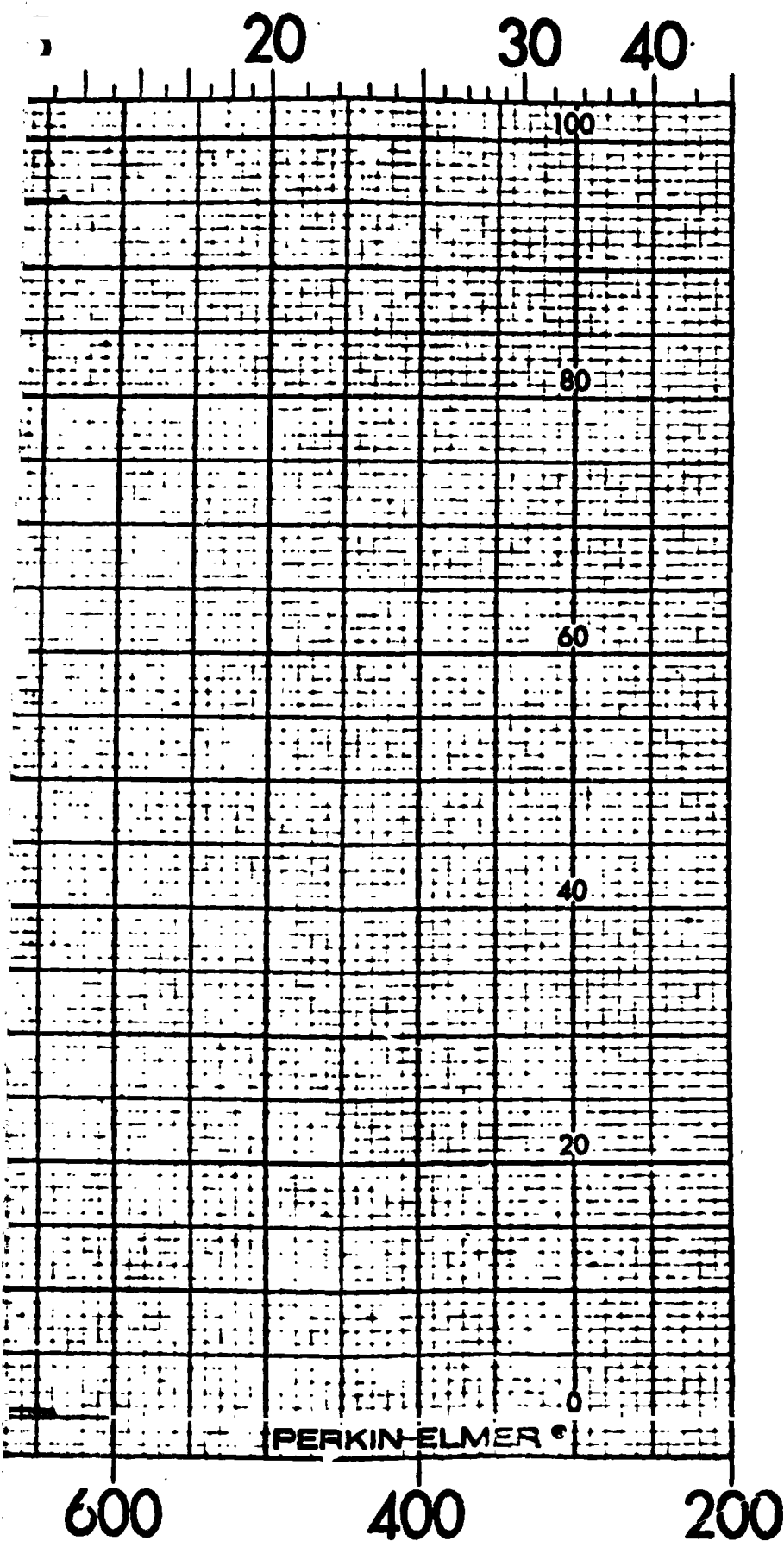
1400

1200

1000

800

600



SPECTRUM NO. B-0327

SAMPLE GAS CELL S/N 108

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 6/9/76

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION _____

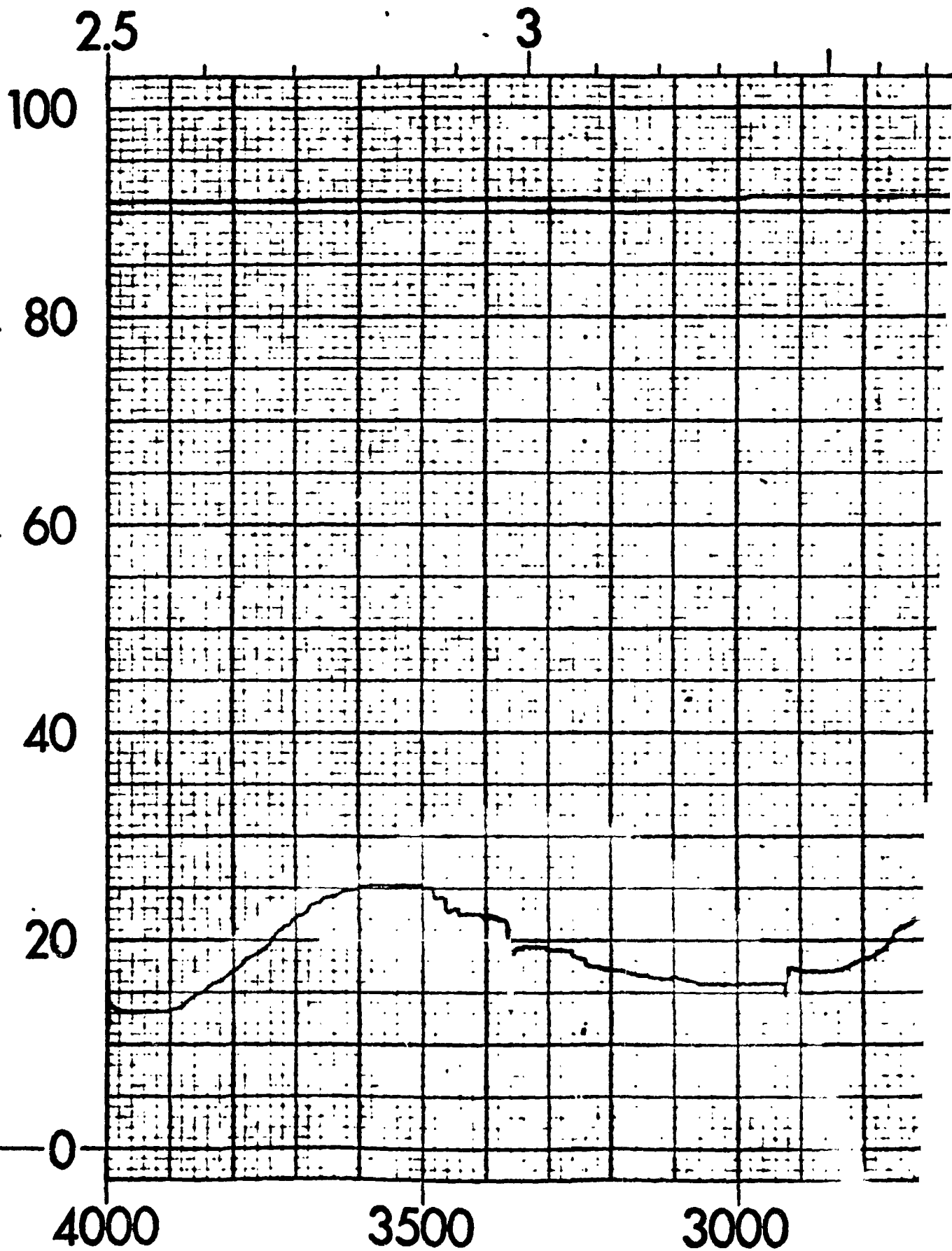
SOURCE CURRENT _____

NO. 221-1607

#22

SAMPLE

TRANSMITTANCE (PERCENT)



FOLDOUT FRAME

WAVELENGTH (MICRONS)

4

5

6

100

100

80

80

60

60

40

40

20

20

0

0

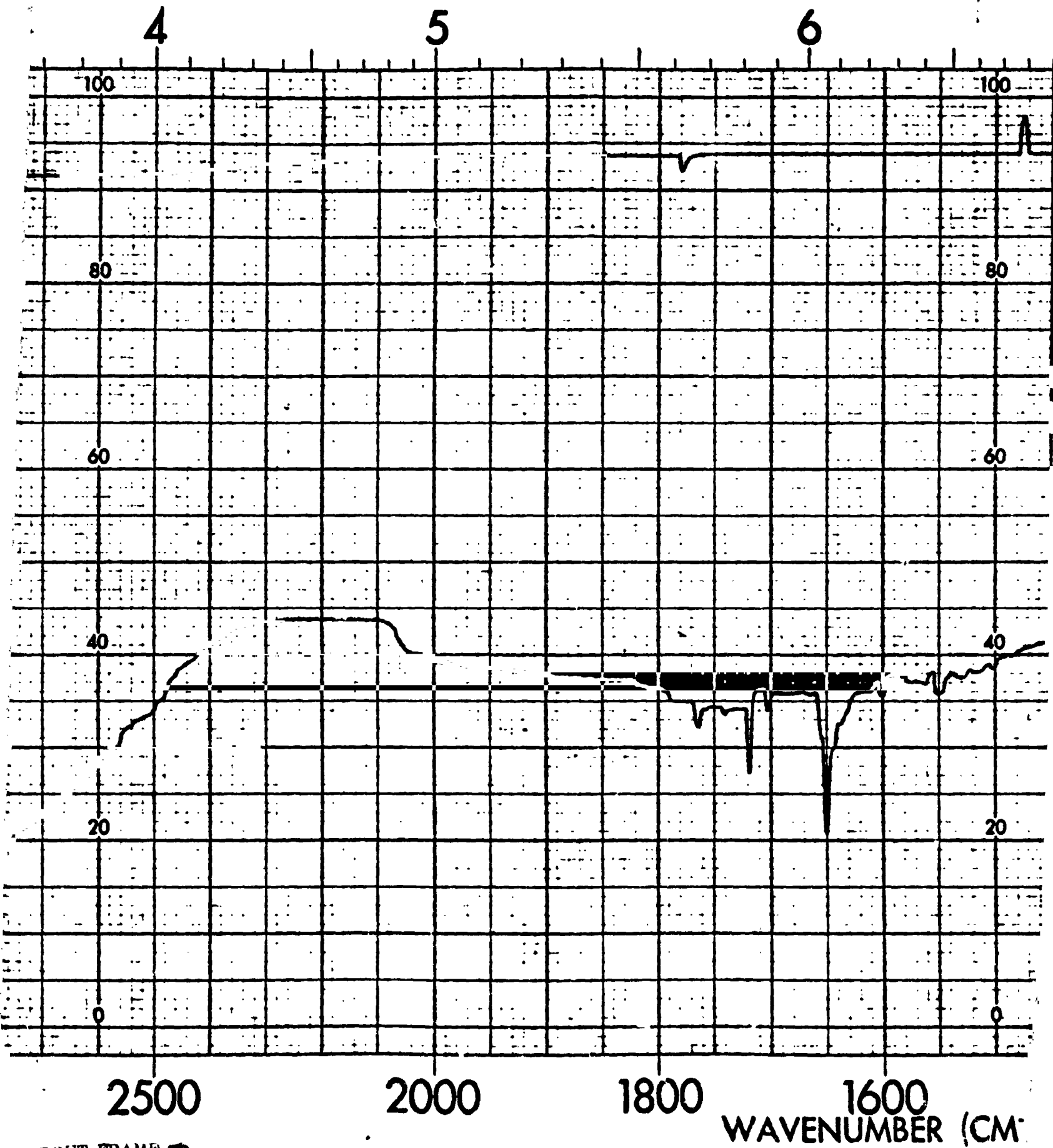
2500

2000

1800

1600

WAVENUMBER (CM⁻¹)



VS)

7

8

9

10

12

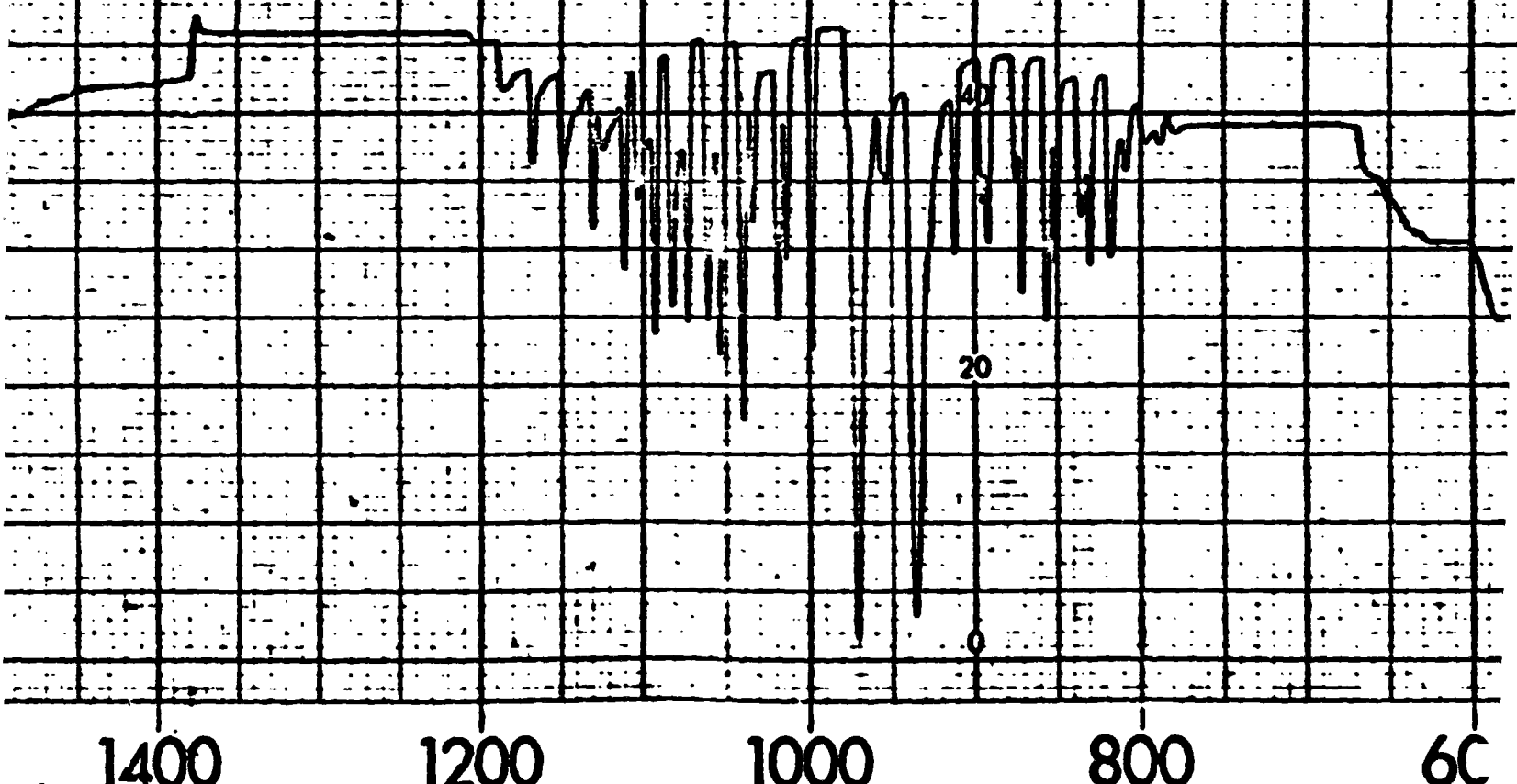
15

100

80

60

20



A-1)

1400

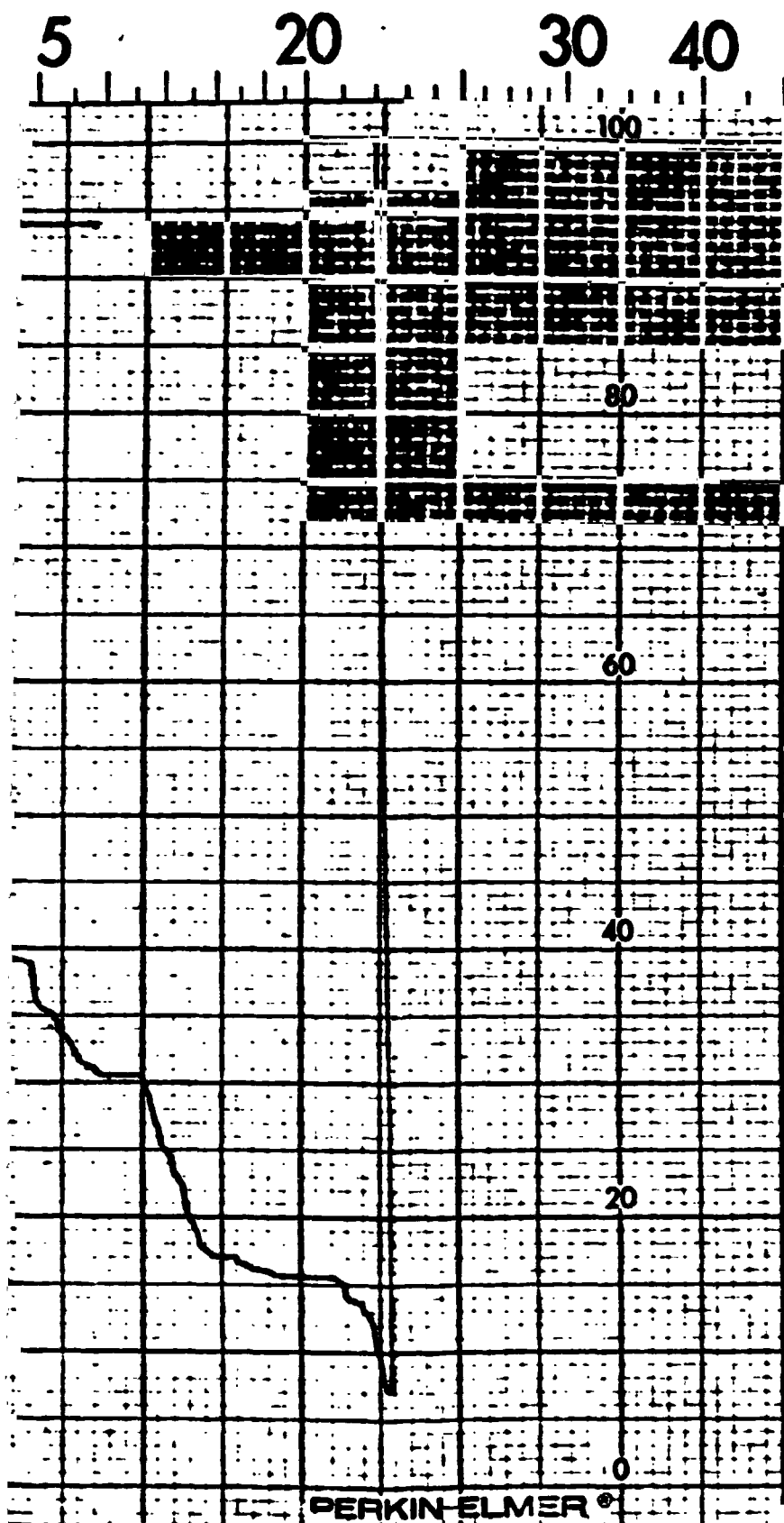
1200

1000

800

600

DOIT FRAME 3



SPECTRUM NO. B-03274

SAMPLE GAS CELL S/N 109

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 6/9/76

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION _____

SOURCE CURRENT _____

600

400

200

NO. 221-1607

I-35

FOLDOUT FRAME 9

63#

SAMPLE

TRANSMITTANCE (PERCENT)

2.5

3

100

80

60

40

20

0

4000

3500

3000

FOLDOUT FRAME

WAVELENGTH (MICRON)

4

5

6

100

100

80

80

60

60

40

40

20

20

0

0

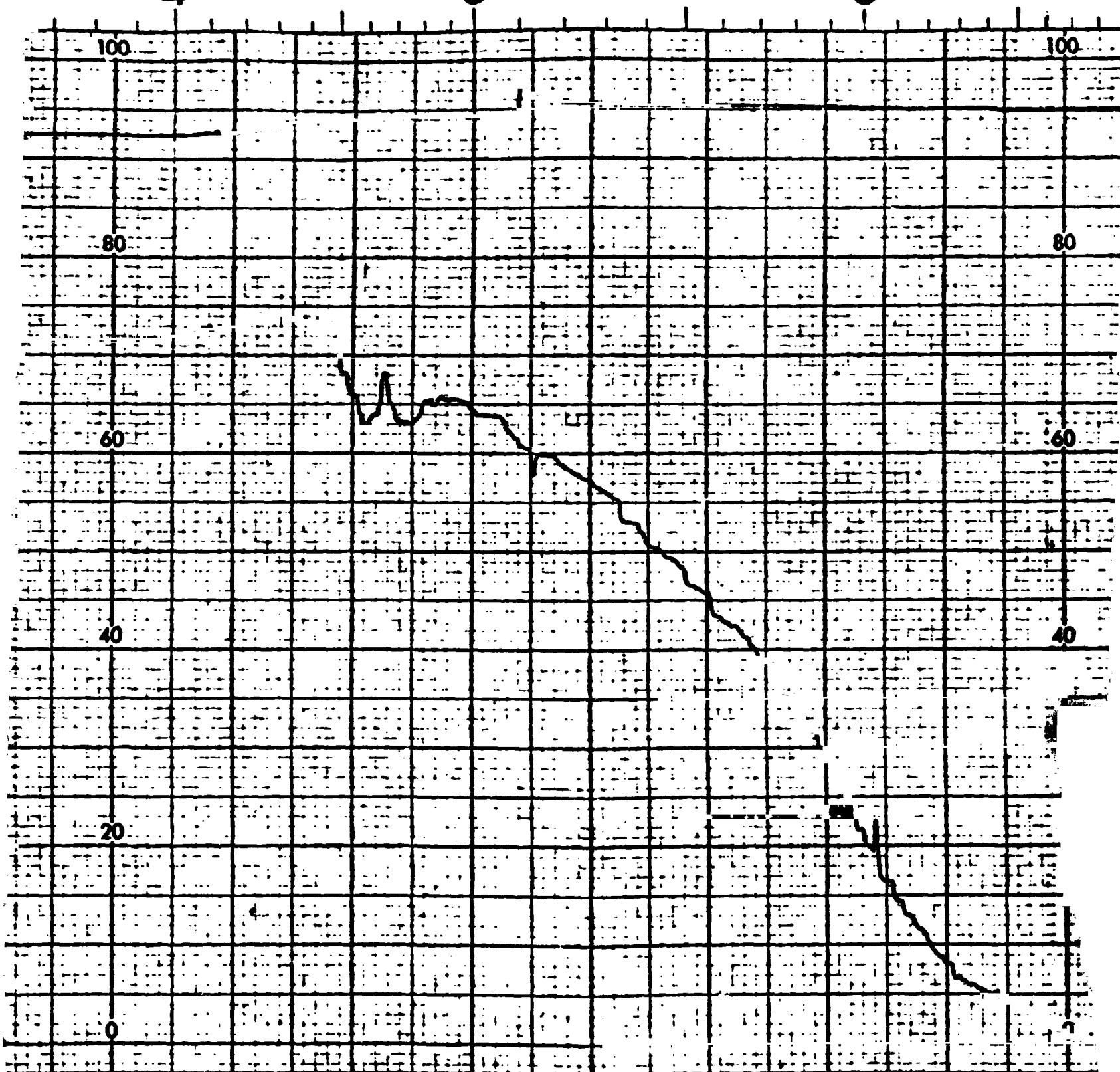
2500

2000

1800

1600

WAVENUMBER (CM⁻¹)



CRONS)

7

8

9

10

12

15

100

100

80

80

60

60

40

40

20

20

0

1400

1200

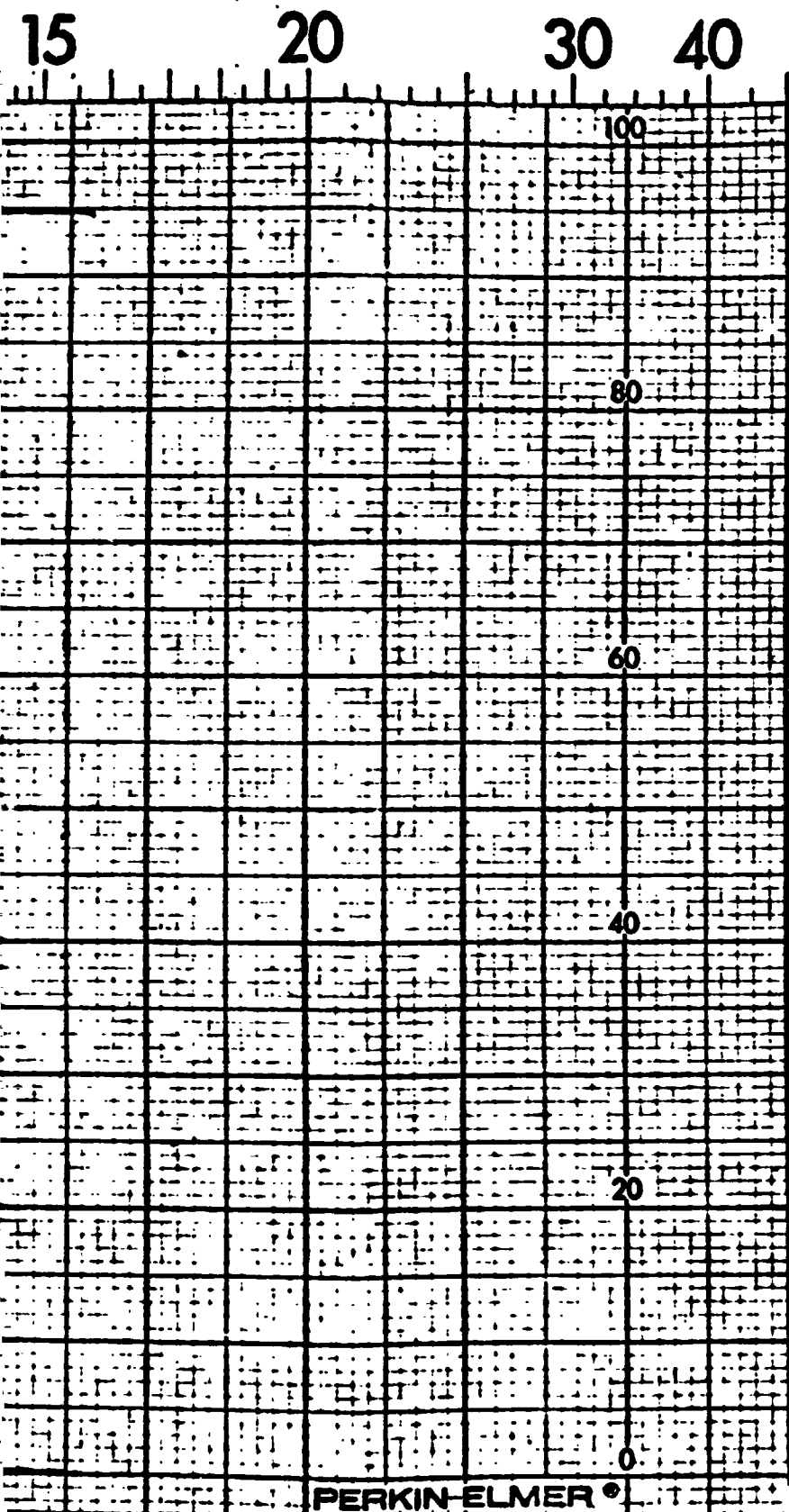
1000

800

(CM⁻¹)

POINT 3

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SPECTRUM NO. B-O 3275

SAMPLE GAS CELL S/N 110

ORIGIN _____

PURITY _____

PHASE _____

THICKNESS _____

1. _____

2. _____

3. _____

DATE 6/9/76

OPERATOR KENNEDY

REMARKS _____

MODEL 521 2:1 SCALE CHANGE _____

SLIT PROGRAM _____

GAIN _____

ATTENUATOR SPEED _____

SCAN TIME _____

SUPPRESSION _____

SCALE EXPANSION _____

SOURCE CURRENT _____

NO. 221-1607

APPENDIX J

**INSTRUCTION MANUAL FOR
GROUND SUPPORT UNIT (G.S.U.)**

**INSTRUCTION MANUAL
FOR GROUND SUPPORT UNIT (G.S.U.)**

**PREPARED BY
BARRINGER RESEARCH LIMITED
304 CARLINGVIEW DRIVE
REXDALE, ONTARIO, CANADA**

**PREPARED FOR
T.R.W. SYSTEMS INC.
ONE SPACE PARK
LOS ANGELES, CALIFORNIA**

OUR REF: TR75-255

OCTOBER 1975

CONTENTS

1. G.S.U. Operating Instructions.
2. N.R.C. Thermocouple Gauge.
3. Blackbody Calibration Source.
4. Lauda/Brinkman Circulator.
5. M.K.S. Capacitance Manometer.
6. Doric Temperature Readout.

GSU OPERATING INSTRUCTIONS

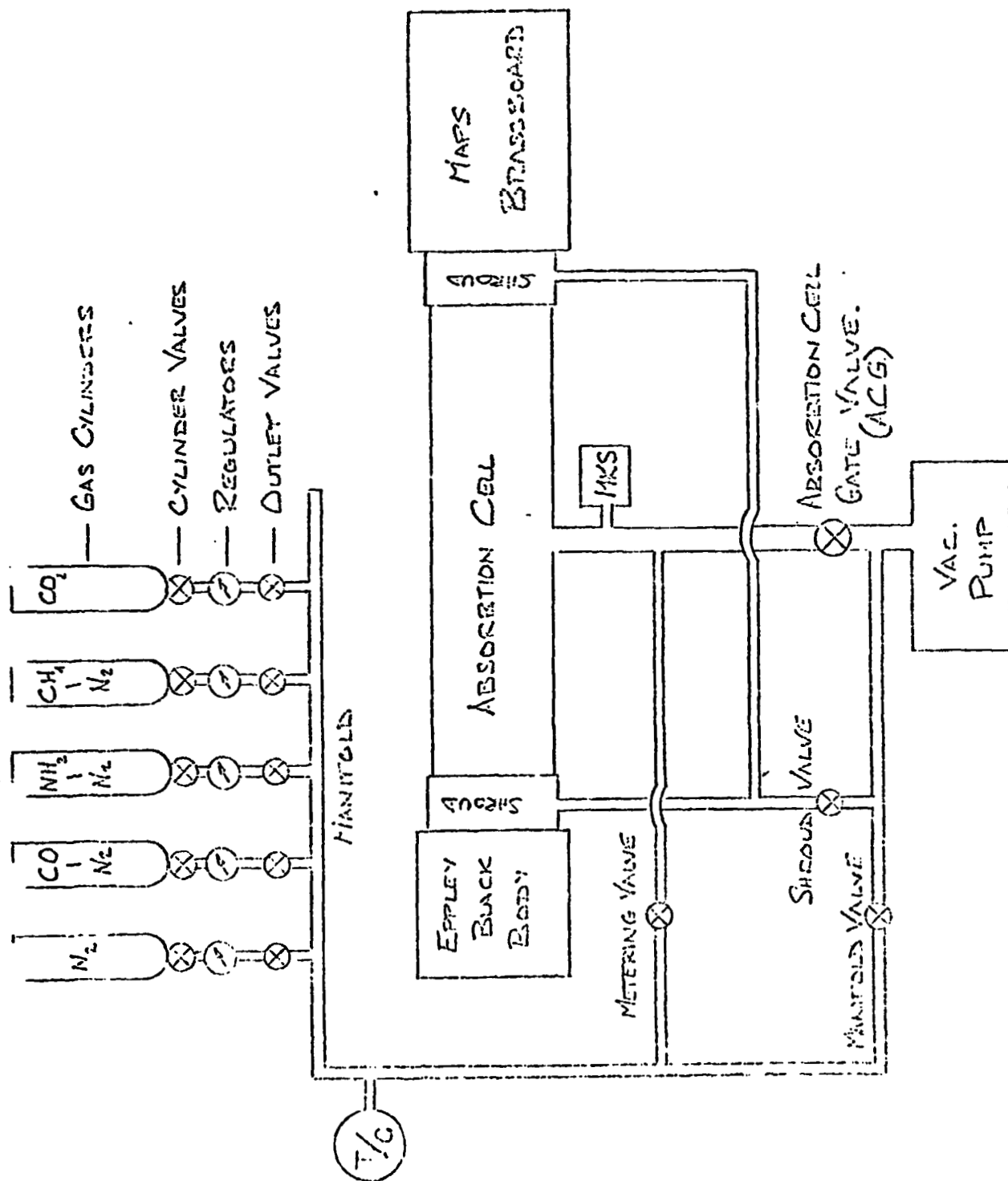
Starting Conditions

<u>Valve or Switch</u>	<u>Position</u>		<u>Location</u>
Absorption cell gate valve	Closed	Fully C.W.	1
Manifold gate valve	Closed	Fully C.W.	2
Shroud gate valve	Closed	Fully C.W.	3
Air admittance valves	Closed	Fully C.W.	4
Metering valve	Closed	Fully C.W.	5
Manifold outlet valves (5)	Closed	Fully C.W.	6
MKS Electronic module	Power On	X 1	7
MKS Digital Readout	Auto	X 1,000	8
Temptronic TE Controller	Power Off		10
Doric Pt. Res. Thermometer	Power On		12
Cell Temp. Readout	Power On	Position No.5	14
Vac pump Circuit breaker	ON		15
Cooler 1 Circuit breaker	ON		16
Cooler 2 Circuit breaker	ON		17
Electronics Circuit Breaker	OFF		18
Heater Circuit breaker	ON		19
Vac pump Powerswitch	OFF		above 15
Cooler 1 Powerswitch	OFF		above 16
Cooler 2 Powerswitch	OFF		above 17
NRC 801 T/C Pressure gauge	Power On	Cell Position	22
Cell temp control	Power Off		23
Lauda K-2R Thermal Control	Compressor ON		Bottom inside
	Line ON		Hammond cabinet
	Thermometer set to -20°C		
	Circulator pump off		

Start up of GSU

POWER Connect power cords to three 115V, 15 amp. receptacles.

PUMP DOWN Switch On pump power switch (20). Switch on electronics circuit breaker and pump out the cell and manifold (open 1 and 2). The pump out should take approximately one hour. (Refer to pump down curve Figure 1). The pressure is monitored on the MKS digital readout in the 760-2 Torr range and on the NRC 801 in the 2 Torr to 1 μ range. (Refer to the MKS and NRC instructions for detailed operation of these systems).



G.S.U. SCHEMATIC

CELL
TEMPERATURE

Set the Cell Temperature Control dial at the desired cell temperature and switch on the C.T.C. power (23). If this temperature is below ambient, switch on cooler λ^2 (21). Monitor the cell temperature on the cell temperature readout thermocouple number 5. For the lowest temperature -27°C the system requires about 10 hours to stabilize, for the highest temperature about 1 hour is required.

BLACKBODY
TEMPERATURE

Switch on cooler number λ^1 (17). After one hour turn on the circulation pump. (Lever on side of cooler). If a low temperature (below -20°C) setting is desired, allow the coolant to circulate for two hours through the blackbody before switching on the Temptronic T.E. Controller. For temperature higher than ambient the T.E. Controller may be switched on as soon as the circulating pump is switched on. Set the T.E. Controller using the calibration sheet supplied in the Eppley Instructions. Prior to switching on the T.E. control, set the Temptronic on high range if the desired temperature is greater than the temperature of the base plate and on the low range if the temperature is lower.

PURGING
REGULATORS

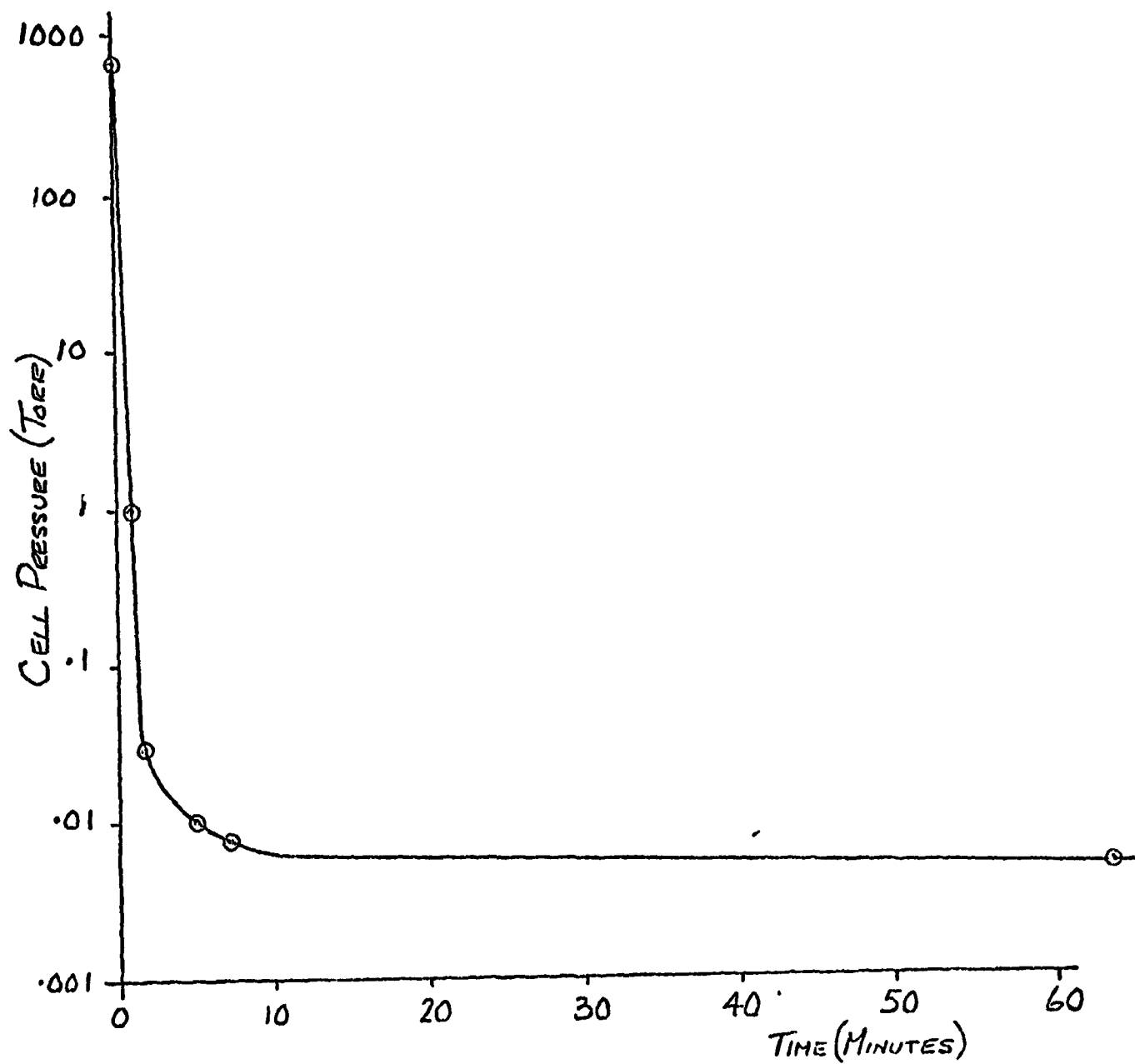
Allow absorption 11 to evacuate to between 1 and 30μ . Close the absorption cell gate valve (AGC). Open the test gas outlet valve and manifold gate valve. Allow the manifold to evacuate to between 1 and 2×10^{-1} Torr on the Varian thermocouple pressure gauge and then close the test gas outlet valve. Open the test gas cylinder valve and adjust the pressure to between 0^* and 45 P.S.I. Open the test gas outlet valve and flow test gas at >2 Torr for about 5 minutes. Shut off test gas outlet valve. Repeat the above regulator pump out procedure with all other test gases. Pump down the manifold to less than 60μ .

FILLING
CELL WITH
TEST GAS

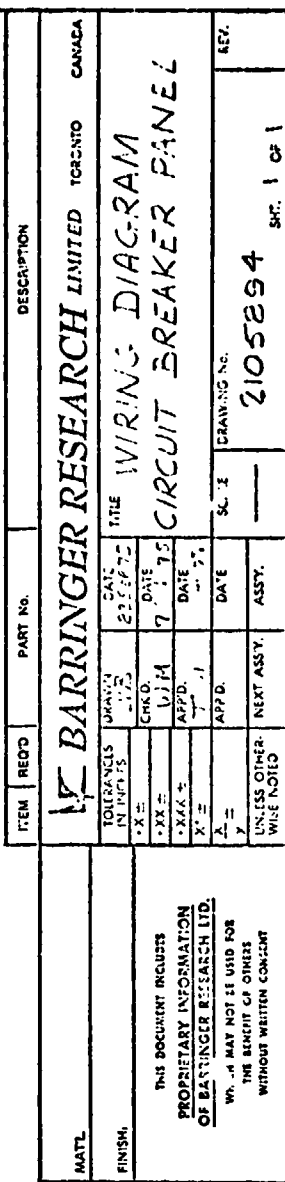
Open the test gas outlet valve $\frac{1}{4}$ turn ccw. Open the metering valve until the change in pressure observed on the MKS pressure gauge readout corresponds to the amount of gas required. Pump out the manifold and add a second gas using the same procedure

* 1 Atmosphere

FIGURE 1



GSU CELL
PUMP DOWN TESTS (MKS GAUGE)
JULY 25th 1975

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2 ALL W21VC- 3x14SJ

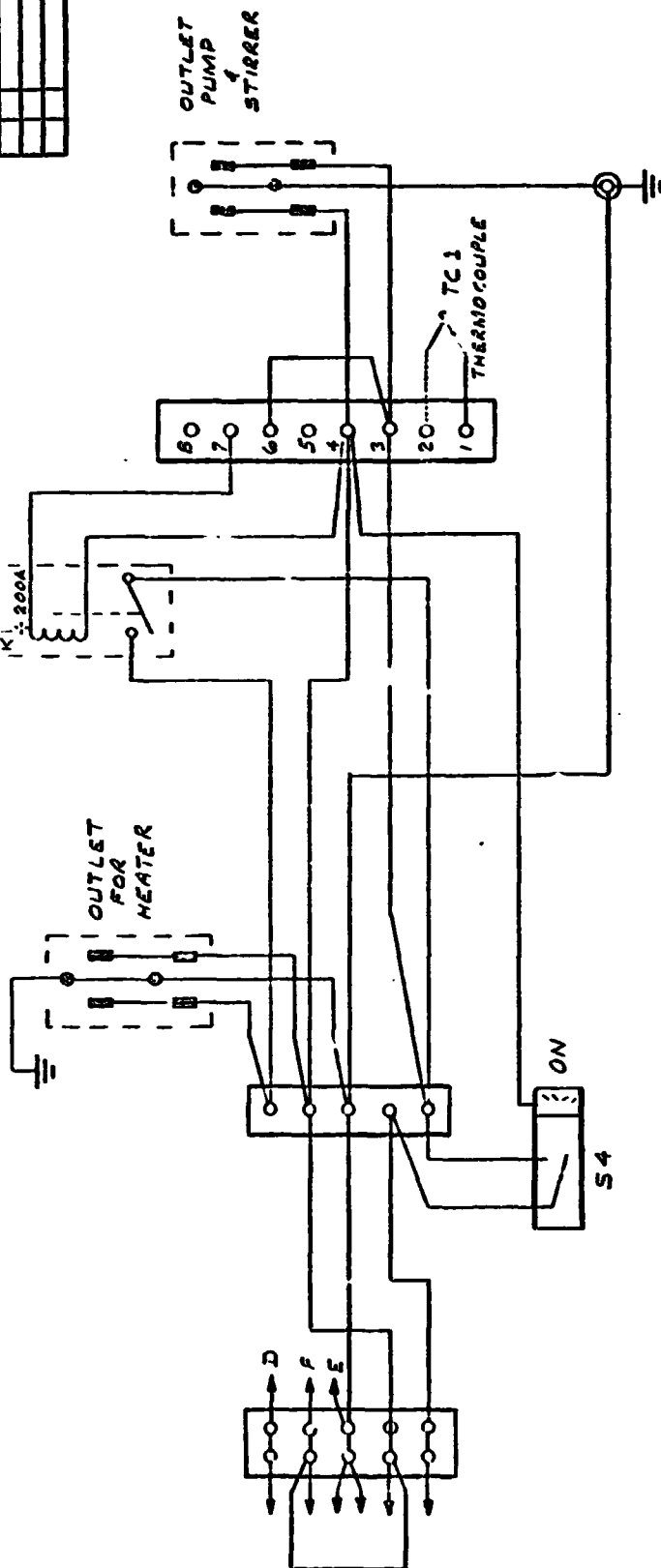
1. REMOVE BURRS & BREAK ALL SHARP EDGES.

NOTES:

4.0 0.00-0.01

196 EXP 024

DRAWING NO.

[illegible]

2. ALL WIRING- 3x14.53

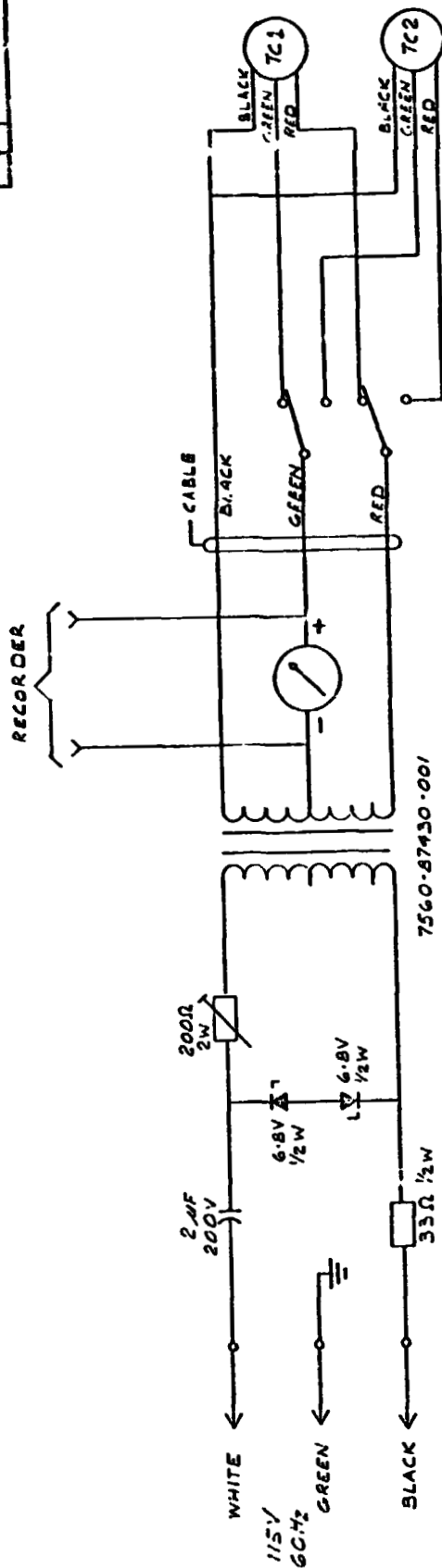
07084-941-08 672

ITEM	REC'D	PART NO.	DESCRIPTION	MATERIAL	FINISH	THIS DOCUMENT INCLUDES PROPRIETARY INFORMATION OF BARRINGER RESEARCH LTD. WHICH MUST NOT BE USED FOR THE BENEFIT OF OTHERS WITHOUT WRITTEN CONSENT	DATE 2005-08-10 TIME 14:00	SCALE 1:1	DRAWING NO. 2105895	REV. 1 OF 1
BARRINGER RESEARCH LIMITED TORONTO CANADA TITLE WIRING DIAGRAM F.T.S. TEMP. CONTROL										

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DO NOT SCALE DRAWING



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ITEM	REQ'D	PART NO.	DESCRIPTION
BARRINGER RESEARCH LIMITED TORONTO CANADA			
TITLE SCHEMATIC THERMOCOUPLE CONTROL			
DATE 23-1-70			
CHECKED BY M			
APPROVED BY M			
DATE 23-1-70			
SCALE —			
DRAWING NO. 210 5803			
SHEET 1 OF 1			
E.L.T.			

THIS DOCUMENT INCLUDES PROPRIETARY INFORMATION OF BARRINGER RESEARCH LTD. WHICH MAY NOT BE USED FOR THE BENEFIT OF OTHERS WITHOUT WRITTEN CONSENT

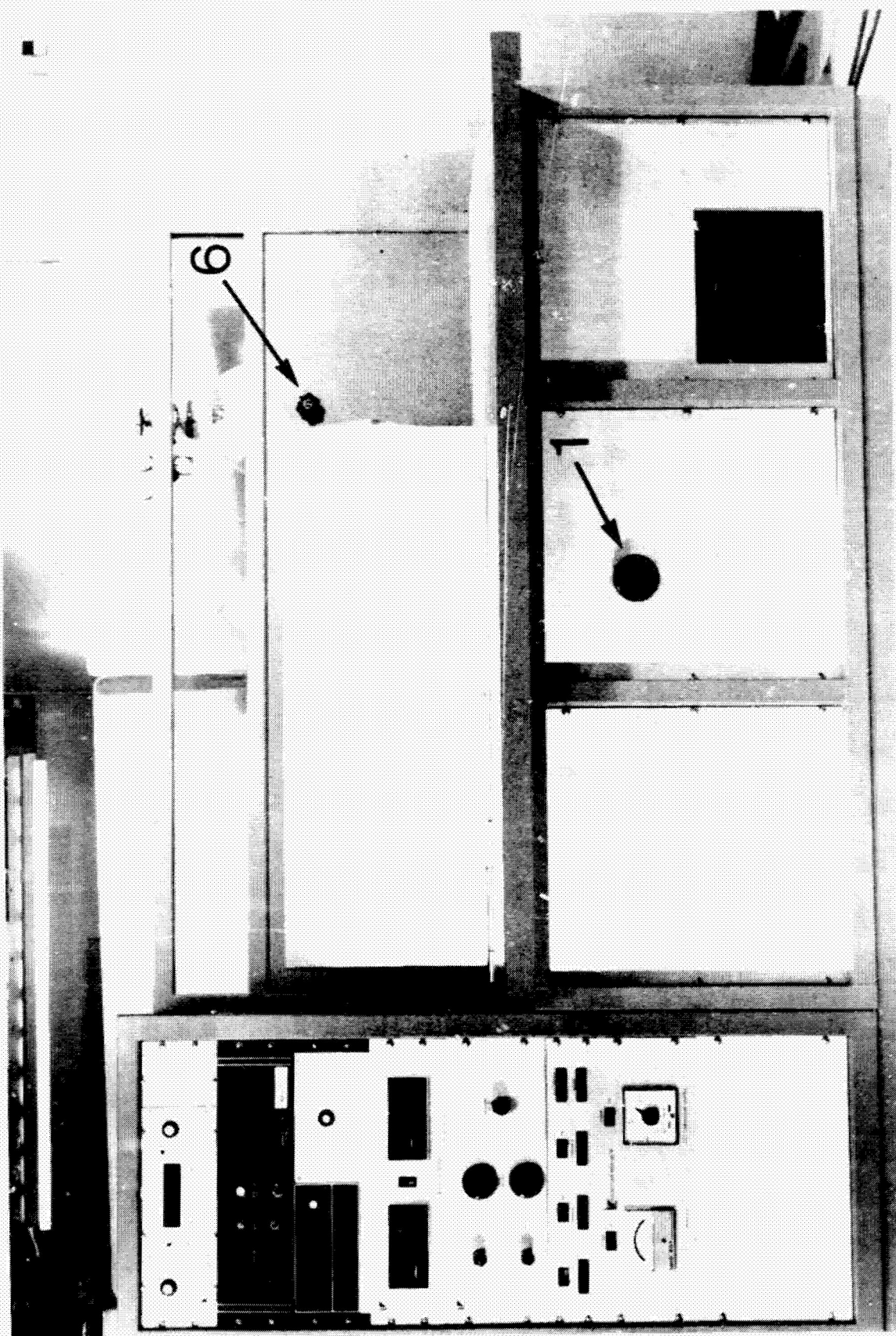
NOTES:

1. REMOVE SURRS & BREAK ALL SHARP EDGES.

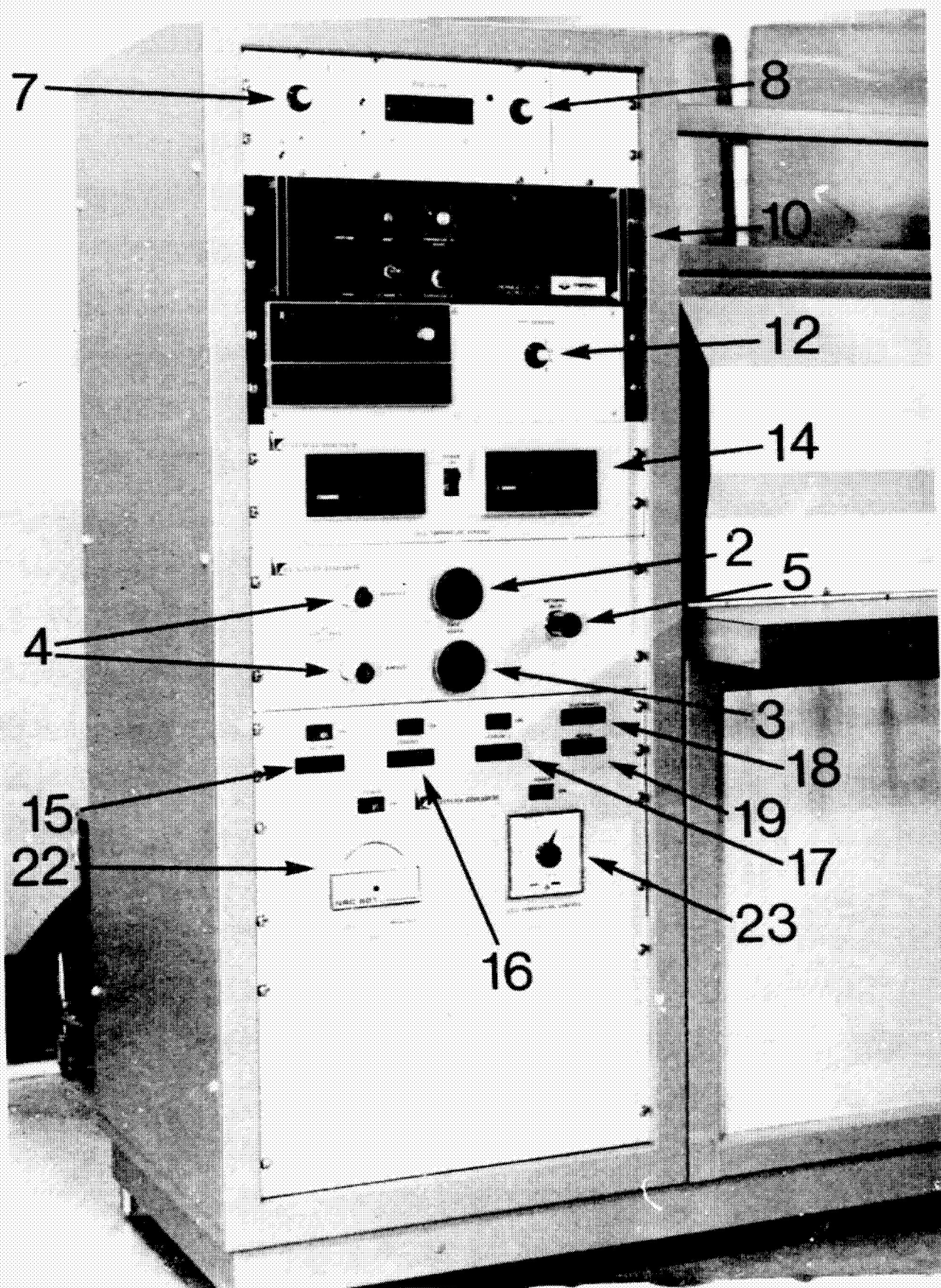
196 EXP 003

GSU INCOMING POWER DISTRIBUTION

Block #	Instruments	Current in Amps	Remarks
(see circuit diagram) I	F.T.S. Heaters	10.2 A	2 x 600 W
	F.T.S. Circulation Pump	0.8 A	
	F.T.S. Stirrer	0.8 A	
	TOTAL	11.8 A	
II	F.T.S Refrigeration	10.5 A	up to 14A Startir current
	Electronics plug strip	2.8 A	
III	Black Body Cooler	9 A	typ. 4-5 amps 6 A starting current
	Vacuum pump	5.5 A	



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NRC 801 THERMOCOUPLE GAUGE CONTROL

INSTALLATION, CALIBRATION AND OPERATING INSTRUCTIONS

The NRC 801 thermocouple gauge control is a compact, self-contained instrument, designed primarily for panel mounting. It is supplied with a 6 ft line cord and a 10 ft thermocouple gauge cable. The instrument is line voltage regulated, and a temperature sensitive element to compensate for temperature drift in thermocouple gauges is built into the thermocouple cable socket. The indicator dial, which covers the pressure range from 1 to 1000 microns (1 micron is 1/1000 of 1 mm of mercury, or 1/1000 of 1 torr) is calibrated for an NRC 521 thermocouple gauge in dry air. The mechanical zero adjust is located on the front of the instrument. The pressure calibration can be reached through a hole in the rear cover (Fig. 1a and 1d). The meter voltage (0 - 11 mv) is available at two solder terminals at the rear for operating remote indicators whose input resistance should be 200 ohms or more.

Installation

A panel cutout, as shown in Fig. 1a, is required for the installation of the NRC 801 thermocouple gauge control. The instrument is mounted from the front and fastened with three nuts supplied (Figs 1b, 1c).

Calibration

1. Adjust the mechanical meter zero until the needle reads OFF.
2. Connect an NRC 521 thermocouple gauge to a vacuum system capable of maintaining a pressure of less than 1.0 micron.
3. Pump down the system to less than 1.0 micron.
4. Connect the thermocouple cable of the NR 801 control to the NRC 521 thermocouple gauge.
5. Plug the line cord into a 115V 50/60 cycle outlet.
6. Turn calibration control in the rear of the instrument until the meter registers Zero microns.
7. Allow the system to stabilize for approximately 15 minutes, and readjust the zero if necessary.

NOTE: If so desired, the gauge can be calibrated against an NRC Patatron^(R) or a McLeod gauge.

Maintenance

Due to aging and/or contamination of the thermocouple gauge, recalibration may be necessary from time to time. The above procedure should then be followed. As the temperature compensation for the TC gauge is built into the TC cord socket, it is not advisable to cut the plug off the TC cord. If the cable is too long, it should be coiled.

Disassembly of Control

The NRC 801 should give years of trouble-free service but, if repairs are necessary, the following procedure of dismantling should be followed.

1. Unplug line cord.
2. Remove the two screws that hold the rear cover and terminals.
3. Slip cover as far back as the cable allow.
4. Unscrew the two spacers.
5. Remove printed circuit card from meter.

NOTE: If, after assembly, the meter reads backwards, turn printed circuit card one-half turn.

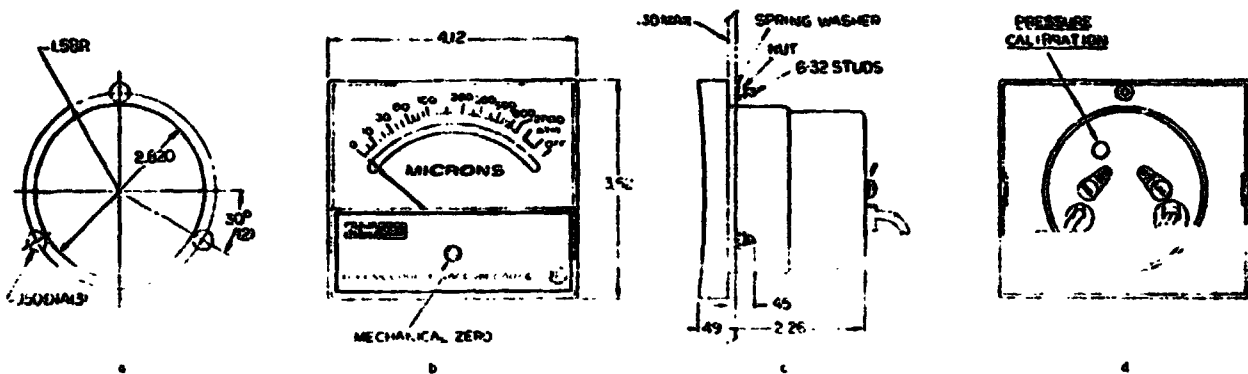


Fig. 1

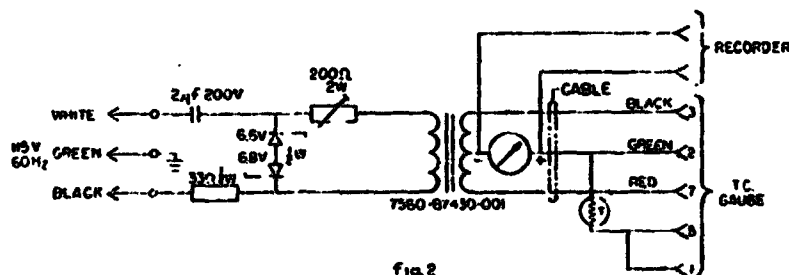


Fig. 2



varian / vacuum division / lexington operation
121 hartwell avenue / lexington / massachusetts 02173

OPERATING INSTRUCTIONS #132-B

LAUDA/BRINKMANN CIRCULATOR

All Models In The K-2/R Series

(Please read the notes on this page)

- CAUTION:**
- 1. This circulator is designed for normally supervised laboratory use. If unattended or over-night operation is required, a suitable back-up safety system should be used in order to prevent possible secondary damage due to leakage or uncontrolled heating. BRINKMANN INSTRUMENTS cannot assume liability for damage to the circulator or the laboratory in which it is located, beyond the replacement, within the warranty period, of defective components as specified in paragraph II.**
 - 2. In order to avoid damage to the compressor and eliminate an excessive starting current which may result in a blown fuse, the compressor should not be turned on for at least 15 minutes after having been turned off. This time interval will permit the Freon to reach the pressure which is needed for a proper start-up.**

(a)

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II. <u>Warranty</u>	1
III. <u>Operating Instructions</u>	1
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PLEASE NOTE: This manual covers models K-2/R and Super K-2/R. The term "K-2/R" as used in the text refers to both models. Differences in specifications and spare parts are indicated wherever applicable.

I. UNPACKING

Please check the packing material carefully to be sure that all components have been received and that nothing is accidentally discarded. The following items must be received:

- identifying numbers refer to Fig. 1, page 2 -

- (1) Bath housing with built-in pump and controls
- (1) Thermoregulator (contact thermometer) -5 to $+105^{\circ}\text{C}$ — (1)
with
Metal sleeve for above — (2) and
Rotating magnet in plastic housing — (3)
- (1) Control (reading) thermometer with tapered joint connection
— (4)
- (1) Piece of hose for temperatures to 150°C (not illustrated)
- (1) Cover for access opening (mounted) — (5)

Any shortage or damage must be reported to your supplier within 7 (seven) days after receipt — see paragraph II.

II. WARRANTY

In lieu of other warranties, either expressed or implied, all LAUDA constant-temperature circulators are unconditionally guaranteed for repair or replacement of all parts (except tubes and thermometers) which become defective due to manufacturing defects or faulty materials, for a period of one year from date of delivery. This warranty is effective only if the instrument is returned to our plant at Westbury, N. Y. for examination and repairs, and becomes void if the equipment has been tampered with unless specifically authorized by us. Damage resulting from misuse of the equipment is not covered by this guarantee, neither will we be responsible for secondary damage due to continued unsupervised use of equipment which has become partially defective. Damage incurred during shipment must be reported to the carrier immediately since an inspection is essential to the settlement of any claim. All packing materials must be retained until their disposal is authorized by the carrier or his representative.

III. OPERATING INSTRUCTIONS

- A. Fill in water to maintain level approximately 1 inch below top of bath. In order to remove the bath cover its handle should be rotated 45° in either direction until it clicks into place in a diagonal position. The cover can then be removed and the circulating liquid should be poured

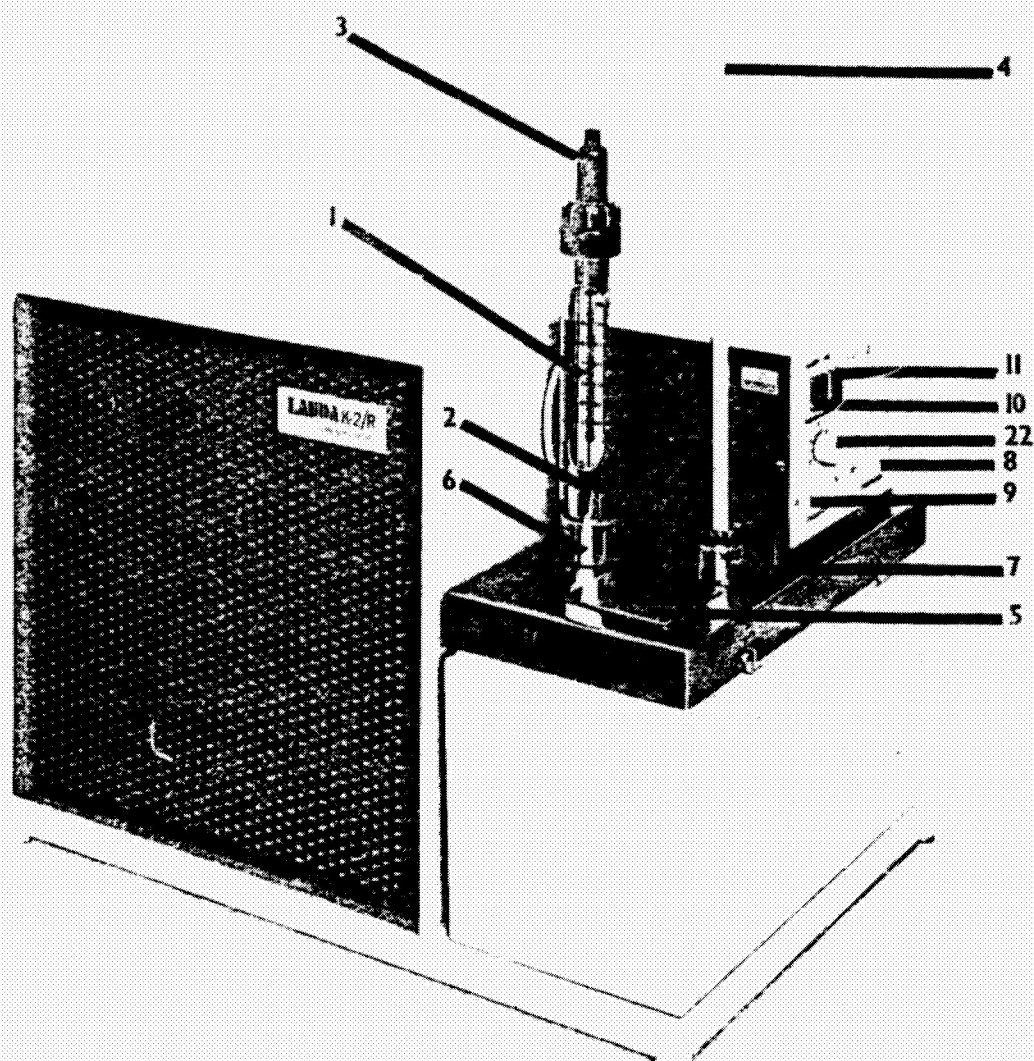


Illustration No. 1

K-2/R Front/Side View

- 1 - Contact thermometer (thermoregulator)
- 2 - Sleeve
- 3 - Rotating magnet
- 4 - Control thermometer (reading thermometer)
- 5 - Bath cover
- 6 - Opening for metal sleeve
- 7 - Tapered opening for control thermometer
- 8 - Sliding switch (compressor)
- 9 - Sliding switch (circulator)
- 10 - Heater indicating light
- 11 - Power indicating light
- 22 - Proportioning Control

into the reservoir within one inch of the top. Since a certain amount of liquid will be required for the external circulating system, the level should be checked after the first few minutes of operation. The cover should then be replaced and locked by rotating the handle 45° in either direction.

- B. For external circulation connect circuit hoses to OUT nozzle (20) and IN nozzle (21). After the instrument has been turned ON and liquid has been circulated through the external system, the internal level should be checked and additional liquid should be added as may be required (see A. above). The K-2/R is designed for external circulation through a closed system only. It is not recommended that this circulator be used for circulation through an open bath or reservoir although this is possible if the external bath level is sufficiently above that of the K-2/R in order to permit a continuous gravity return. In this case, the control valve (14) must be adjusted in such a way that the pumping rate will not exceed the gravity return rate.
- C. Without external circulation — Connect a short piece of hose across nozzles 20 and 21. This connection is necessary because the amount of internal agitation is directly related to the flow rate through the above-mentioned nozzles as controlled by lever 14.
- D. Supplier's Instructions for K-2 Series Circulators which are equipped with Duplex Pumps (K-2/D and K-2/RD).

Duplex pumps consist of separate pressure and suction sections which are connected to one and the same motor. The suction section operates continuously at its maximum flow rate. The rate of liquid which is pumped out by the pressure section is continuously regulated by a float-operated valve which will increase or decrease the output in order to maintain a constant level within the internal reservoir. For additional information on the operation and performance of Duplex pumps, please read the following paragraphs:

- a. This pump can be used both for circulating in a "closed" circuit, through an external, jacketed appliance, or for circulating through a "broken" circuit such as an open water bath. In the latter case, the open ends of the two hoses from the circulating nozzles are merely immersed in the liquid of the open bath; return to the circulator is accomplished by the suction state of the pump. To balance possible variations between the pressure and suction stages, the pump is equipped with a floating valve regulator which controls the amount of liquid flowing out of the circulator; thus maintaining a constant niveau (level) in the circulator within an accuracy of ± 1 mm. The external (open) bath may be mounted 1 meter higher or lower than the circulator without disturbing this relationship.
- b. When first placing the system in operation, fill the external bath to the desired height. The circulator maintains its own level and the external bath must be filled accordingly.

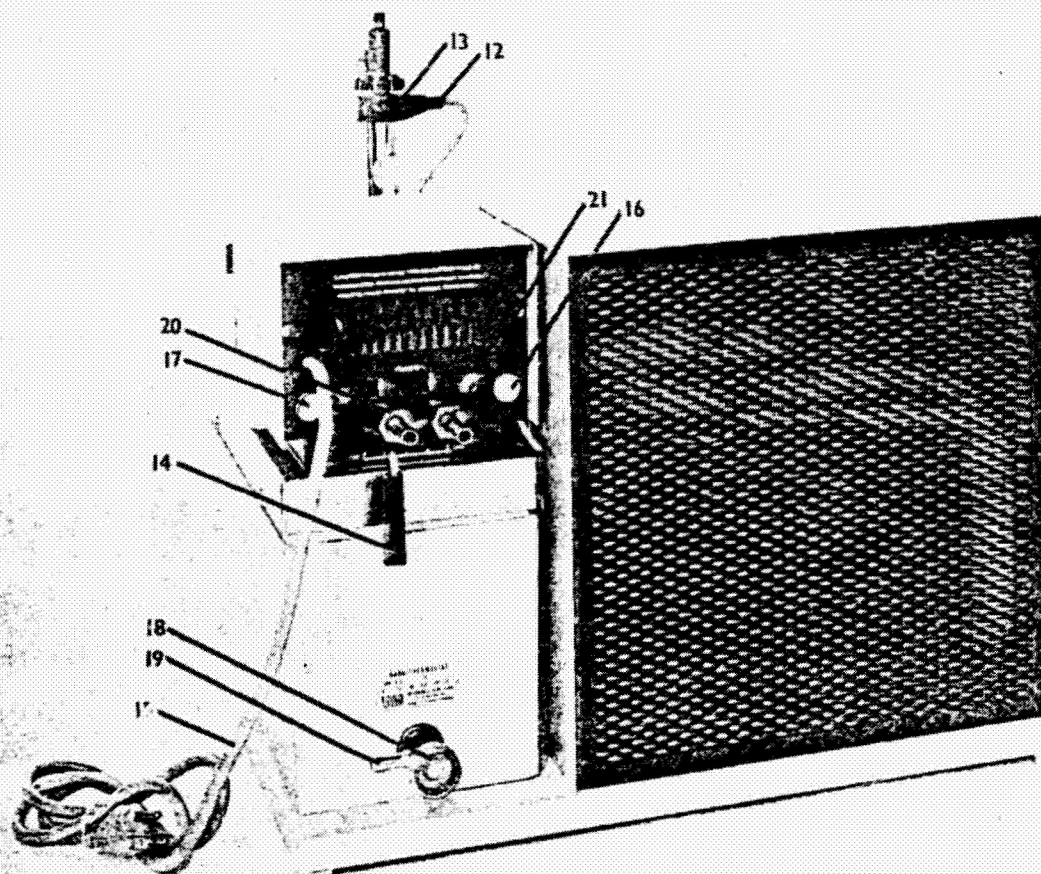


Illustration No. 2

K-2/R Rear View

- 12 - Female plug of connecting cable
- 13 - Male receptacle on contact thermometer
- 14 - Control valve lever
- 15 - Line cord
- 16 - Locking screws for upper housing
- 17 -
- 18 - Drain valve knob
- 19 - Drain valve nozzle
- 20 - Circulating pump nozzle OUT
- 21 - Circulating pump nozzle IN

- c. The front nozzle of the pump is the pressure side and the rear nozzle is the suction side. If an open bath is tempered by simply immersing the open ends of the hose in the external bath, it is advisable to cut the hose end at a slant (diagonal cut) to eliminate any possibility of the suction hose attaching itself to the inside of the tank wall (by suction) and cutting off the return flow of liquid.
 - d. Trouble-free circulating operation can only be guaranteed if the circulated liquid does not have a viscosity higher than 50 cP at 20 °C.
 - e. The flow-control valve is not as effective on the Duplex pump as on the Simplex version because of varying forces in the pressure and suction side and because of the floating valve. Therefore, with the Duplex pump, this valve should normally be open (pushed to the front) or closed (pushed to the rear). Generally, this is not a disadvantage because even when circulating through a small external system (capacity 1 liter), there is no evidence of a violent reaction (waves) in the external bath.
 - f. If a system with a Duplex pump is used for circulating through a closed circuit (refractometer, spectrophotometer, viscometer, etc.,) the liquid in the circulator must be filled within 30 mm (1-1/2") of the top. Otherwise, the rate of circulation may be restricted by the floating valve in the pressure side. This valve closes as the bath level falls. If the liquid level is insufficient, it will continue to stay closed in an effort to suck liquid out of the other side of the circuit. Do not forget that liquid fills the hose circuit which may require that some refilling of the bath is necessary. Ideally, for closed circuit operation, the floater of the pump in the bath should be as close as possible to the top of the circulator tank.
- E. Adjust lever 14 for the rate of flow which is required. Flow rate is zero when the lever is on the extreme right; do not select maximum flow rate until circulator has been turned on.
 - F. Install metal sleeve (2) for thermoregulator in opening (6) provided and push down firmly. End of sleeve closest to center of cut-out for scale must be at top.
 - G. Install thermoregulator (1) by gently but firmly pushing it into sleeve. Push down as far as it will go. Then connect two-prong plug on line from left side of circulator to connectors on thermoregulator. Now, mount rotating magnet in housing (3) on top of thermoregulator and adjust temperature setting on scale by rotating magnet (see para. IV.).
 - H. Install reading thermometer (4) into tapered opening (7).
 - I. Connect three-prong plug attached to end of line cord (15) to a 115 V A. C., 60 cycle outlet, fused for a minimum of 10 amps.

J. The circulator can now be turned "ON" by sliding switch (9) towards the right. In this position a red dot on the left side of the switch will be exposed; the right-hand pilot light (11) will light up at full intensity. For operation above 40 °C the compressor switch (8) should be in the OFF position. At all temperatures below 40 °C this switch should be ON.

K. The K-2/R is equipped with a solid state triac controlled electronic relay which also includes a wattage proportioning control (22) and a noise suppression circuit. The proportioning control can be set for 20-100% of the maximum rated output (750 Watts). For initial heat-up or maximum heating, the proportioning control should be set to 10 (100%). When the circulator cycles at its operating temperature, as indicated by the heater light (10), the control accuracy can be increased by reducing the proportioning control to a setting at which the ratio of heating vs. non-heating cycles is approx. 1:2. If the proportioning control is set too low, the heater will stay on continuously because the wattage output will not be high enough to overcome the cooling effect of the refrigeration system which is operating at all times. Very brief and infrequent heating pulses are indicative of a proportioning setting which is too high, and thus, results in excessive temperature variations.

IV. USE OF THERMOREGULATORS

A. Setting the Temperature (control point) — Proceed as follows:

1. After loosening the locking screw on the magnet housing, place the magnet on top of the contact thermometer.
2. On the upper (exposed) scale of the thermoregulator there is a small horizontal black bar which moves up or down on a spindle depending on the direction in which the magnet is rotated.
3. Rotate the magnet in the desired direction until the top of the moving bar is approximately level with the desired temperature on the scale. Clockwise rotation increases the set point; counter-clockwise rotation lowers the temperature. One complete turn on the standard -35/+105 °C thermometer is equal to a change of approximately 0.5 °C. Then lock the magnet with screw.
4. After putting the bath in operation, the temperature will stabilize near the set point. However, some adjustment is usually necessary since the operating temperature may be 1 °C above or below the desired temperature. To assist the user, each magnet housing is calibrated and the change in temperature, per division of rota-

tion, can be determined with the particular thermoregulator being used. On the thermoregulator $-35 / +105^{\circ}\text{C}$ one division on the magnet scale represents a temperature change of approximately 0.05°C . In adjusting the thermoregulator, the switching point (point at which the operating temperature exactly equals the set temperature) can be determined visually with the aid of the signal lamp (10). When heating is required, this lamp is ON.

5. For operation at temperatures above 100°C we now deliver only the longer stem thermoregulators which must be used with the long metal support sleeve. This was done because experience has shown that if the scale is left in the bath liquid at high temperatures, the mercury may be distilled only to condense again at a higher, cooler location. This shortens the mercury column of the thermoregulator (breaking contact) which causes the system to call for heat while the actual temperature climbs steadily beyond the control point. By mounting the scale above the bath liquid, this problem has been eliminated on our baths.
6. When not in daily use, always set the thermoregulator above room temperature (if possible). This prevents continuous contact between the contact wire and the mercury column.

B. Trouble Shooting the Thermoregulator

It is possible that due to shock encountered in transportation, the mercury column in the thermoregulator has separated. To remedy this, proceed as follows:

1. Rotate the magnet until the reading bar on the face of the thermoregulator is above the scale.
2. Carefully heat the mercury bulb of the thermometer over a small flame until the mercury column rises into the excess temperature collector, between upper and lower scales, where it will rejoin.
3. Cool thermometer slowly. If mercury does not rejoin, it may be necessary to heat again until it collects in the neck between the two scales. Then tap bulb of thermometer on a soft padded surface and shake out manually.

C. Testing Defective Thermoregulator

If the circulator does not function correctly — heater does not begin to operate and system does not maintain temperature — the thermoregulator may be defective. To test, proceed as follows:

1. Disconnect cable and plug (12) from receptacle on thermoregulator.

2. Short-circuit the connecting plug (12) by inserting a piece of wire. The signal lamp (10) must go off. If it does not go off and does not disengage the heater, the defect must be in the control circuit.

V. OPERATION IN VARIOUS TEMPERATURE RANGES

- A. The K-2/R is equipped with contact and control thermometers which cover a range of -35 to $+105^{\circ}\text{C}$. If this circulator is to be used at temperatures above or below the above-mentioned range it will be necessary to obtain additional thermometers which are listed in the LAUDA catalog. PLEASE NOTE that adjacent to each contact thermometer we list the length of the metal protecting sleeve with which it must be used. The K-2/R comes equipped with a short sleeve; it follows that, if one purchases a thermometer which requires a long sleeve, such a sleeve should be purchased at the same time. In lieu of additional thermometers it may be more convenient to use a platinum resistance thermometer with the R-20 temperature controller.
- B. Below $+1^{\circ}\text{C}$ — We recommend a 50:50 Methanol/water mixture. Please use distilled water only. Switches (8) and (9) must be in the ON position. For external circulation we would recommend the use of our foam-rubber insulated silicone hose. Cat. No. 27 59 200-7.
- C. From $+1$ to $+40^{\circ}\text{C}$ — We recommend the use of distilled water. Operation is the same as listed under "B" above.
- D. From $+40$ to $+95^{\circ}\text{C}$ — We suggest the use of distilled water. The compressor switch (8) must be in the OFF position. For external circulation we recommend our perbunan hose, Cat. No. 27 59 100-1.
- E. From $+95$ to $+150^{\circ}\text{C}$ — We recommend the use of special liquids as listed in paragraph VI. The compressor switch (8) must be left in the OFF position at all times. For external circulation use perbunan hose. Cat. No. 27 59 100-1.

VI. RECOMMENDED CIRCULATING LIQUIDS

- A. Distilled water ($+1$ to $+95^{\circ}\text{C}$)
- B. Methanol (-70 to $+50^{\circ}\text{C}$) — Although Methanol is toxic, we do recommend its use if it is handled with reasonable care. For operation from -10°C to ambient, it may be diluted with water on a 50/50 basis.
- C. Ultra-Therm 250 W ($+20$ to $+250^{\circ}\text{C}$) — Cat. No. 27 57 010-1 — Our own mixture. A hydrocarbon oil which is water soluble for easy exchange. It is not transparent and has a distinct brown/green color.
- D. Silicone Oils (-30 to $+150^{\circ}\text{C}$) — a phenyl-methyl silicone oil but one having a very low viscosity of 5 cST at 20°C .
 1. Type SK Frigor (-60 to $+120^{\circ}\text{C}$) — Cat. No. 27 57 100-0.
 2. Type SK Super-Frigor (-60°C to $+120^{\circ}\text{C}$) — Cat. No. 27 57 110-7.

VII. SUGGESTED HOSES FOR EXTERNAL CIRCULATION AND MISC. ACCESSORIES

- A. Foam-rubber insulated silicone hose, 8 mm i.d., 30 mm o.d., Cat. No. 27 59 200-7
- B. Silicone hose, 8 mm i.d., for use to -55°C, not insulated. Cat. No. 27 59 180-9.
- C. Perbunan hose, 9 mm i.d., for use to +150°C, Cat. No. 27 59 100-1.
- D. Test tube holder for 5 (five) test tubes. Cat. No. 27 53 890-0.

VIII. PERFORMANCE DATA

Operating Range	: -10 to +150°C — K-2/R -20 to +100°C — Super K-2/R
Sensitivity	: ±0.01°C
Control Accuracy	: ±0.01 to 0.02°C (measured with distilled water as circulating liquid)
Cooling Performance (*) (without load)	: Net available cooling capacity at -10°C approximately 200 BTU/h — K-2/R approximately 150 BTU/h — Super K-2/R
Heating Wattage	: 750 Watts
Reservoir Liquid Required	: Approximately 1 (one) gallon
Pumping Capacity	: 2-1/2 gal/min.

(*) If compressor has not been used for 24 hours or longer the cooling performance will reach this level only after several hours of compressor operation.

IX. PARTS LIST

<u>Cat. No.</u>	<u>Parts Description</u>
<u>Thermometers</u>	
27 59 980-0	Contact thermometer type 215F (fork-type) -35 to +105°C
27 59 690-8	Control (reading) thermometer type 125, -35 to +105°C
27 53 400-7	Short protective sleeve for contact thermometer
27 53 420-1	Rotating magnet drum
<u>Compressor</u>	
27 57 940-0	Compressor (condensing system) Tecumseh type AE6H (K-2/R)
27 56 060-1	Compressor (condensing system) Tecumseh type AE5I (Super K-2/R)

X. SERVICE

A. Refrigeration

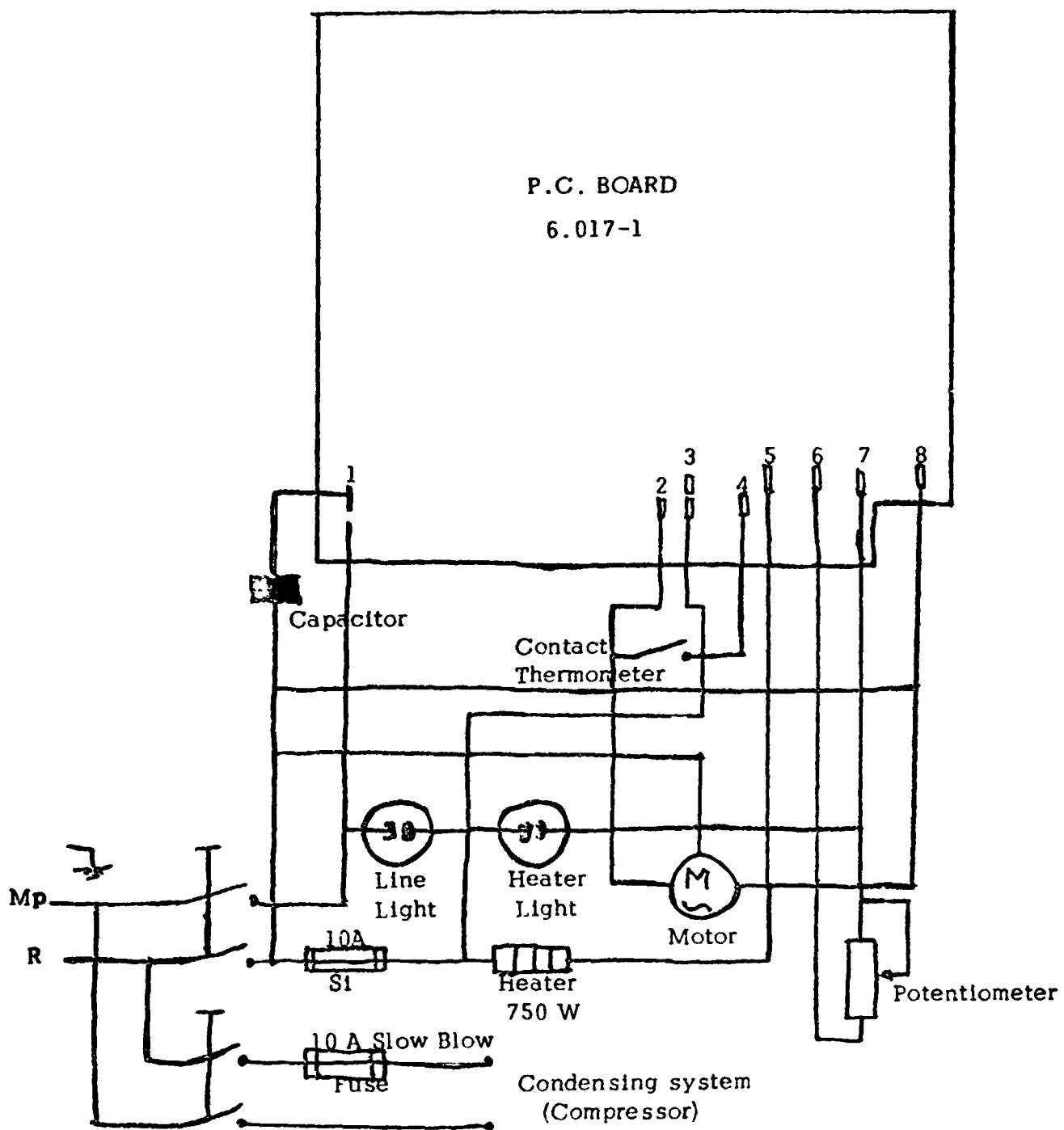
	K-2/R	Super K-2/R
Compressor:	Tecumseh AE 6 H	Tecumseh AE 5 L
Refrigerant:	Freon 12 - approx. 5 oz.	Freon 12 - approx. 8 oz.
Suction pressure:	10 psi after 15 min. running time	5 psi after 15 min. running time

B. General

Any Lauda constant-temperature circulator, or component thereof, may be returned to our shops in New York for service, overhaul or replacement of parts.

For information, contact:

LAUDA INSTRUMENTS DIVISION
BRINKMANN INSTRUMENTS INC.
Westbury, New York 11590
Phone (516) 334-7500
TWX 510 222 8254



K-2/R CIRCUIT CONNECTIONS
 -units with serial # 5000 or higher-

-Fig. 4-